NEHRU COLLEGE OF ENGINEERING AND RESEARCH CENTRE
(NAAC Accredited)
(Approved by AICTE, Affiliated to APJ Abdul Kalam Technological University, Kerala)

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

COURSE MATERIAL

EE 208 MEASUREMENTS AND INSTRUMENTATION

VISION OF THE INSTITUTION

To mould our youngsters into Millennium Leaders not only in Technological and Scientific Fields but also to nurture and strengthen the innate goodness and human nature in them, to equip them to face the future challenges in technological break troughs and information explosions and deliver the bounties of frontier knowledge for the benefit of humankind in general and the down-trodden and underprivileged in particular as envisaged by our great Prime Minister Pandit Jawaharlal Nehru

MISSION OF THE INSTITUTION

To build a strong Centre of Excellence in Learning and Research in Engineering and Frontier Technology, to facilitate students to learn and imbibe discipline, culture and spirituality, besides encouraging them to assimilate the latest technological knowhow and to render a helping hand to the under privileged, thereby acquiring happiness and imparting the same to others without any reservation whatsoever and to facilitate the College to emerge into a magnificent and mighty launching pad to turn out technological giants, dedicated research scientists and intellectual leaders of the society who could prepare the country for a quantum jump in all fields of Science and Technology

ABOUT DEPARTMENT

- Established in: 2002
- Courses offered : B.Tech in Electrical and Electronics Engineering

  M.Tech in Energy Systems
- Approved by AICTE New Delhi and Accredited by NAAC
- Affiliated to the A P J Abdul Kalam Technological University.

DEPARTMENT VISION

To excel in technical education and research in the field of Electrical & Electronics Engineering by imparting innovative engineering theories, concepts and practices to improve the production and utilization of power and energy for the betterment of the Nation.

DEPARTMENT MISSION

- To offer quality education in Electrical and Electronics Engineering and prepare the students for professional career and higher studies and to make students socially responsible
- To create research collaboration with industries for gaining knowledge about real-time problems.

PROGRAM OUTCOMES (POS)

Engineering Graduates will be able to:

1. **Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
2. **Problem analysis**: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of

mathematics, natural sciences, and engineering sciences.

3. **Design/development of solutions**: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
4. **Conduct investigations of complex problems**: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
5. **Modern tool usage**: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.
6. **The engineer and society**: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
7. **Environment and sustainability**: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
8. **Ethics**: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
9. **Individual and team work**: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
10. **Communication**: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
11. **Project management and finance**: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.
12. **Life-long learning**: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

PROGRAM SPECIFIC OUTCOMES (PSO)

PSO1: Ability to Formulate the various static characteristics of measuring systems with errors and to investigate the future scope for calibration systems.

PSO2: Ability to learn and solve the problems related to two and three wattmeter method of power measurement and about different galvanometers

PSO3: Ability to inculcate the Knowledge for analyzing different simulation software used for measurements and virtual instrumentation systems for online measurements and analysis

Note: H-Highly correlated=3, M-Medium correlated=2, L-Less correlated=1

CO'S	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
C208.1	2	1										
C208.2	3	1										
C208.3	3	1										
C208.4	3											
C208.5	3				1							2
C208.6	3				2							2
C208	2.83	0.5			0.5							0.66

SUBJECT CODE: EE208	
COURSE OUTCOMES	
C208.1	Identify and analyse the factors affecting performance of measuring system
C208.2	Choose appropriate instruments for the measurement of voltage, current in ac and dc measurement.
C208.3	Explain the operating principles of various ammeters, voltmeters and ohm meters
C208.4	Describe different flux and permeability measurements methods
C208.5	Identify different AC potentiometers and bridges,
C208.6	Identify the transducers for physical variables and to describe operating principle

CO'S	PSO1	PSO2	PSO3
C208.1	3	3	3
C208.2		3	3

C208.3	3		
C208.4		3	3
C208.5	3		
C208.6			2
C208	3	3	2.75

MODULE NOTES

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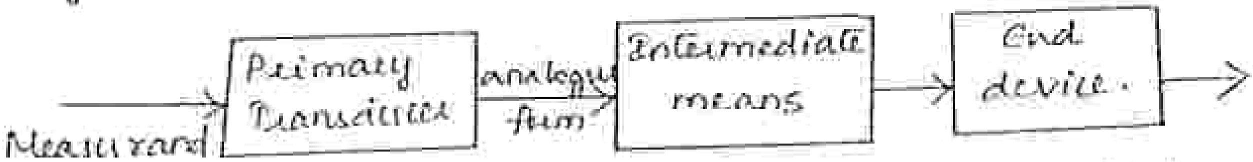
MODULE-1.

GENERAL PRINCIPLES OF MEASUREMENTS.

MEASUREMENT SYSTEM :-

A measuring instrument exists to provide information about the physical value of some variable being measured. In simple cases, an instrument consists of a single unit which provides an output reading or signal according to the magnitude of the unknown variable applied to it. However, in more complex measurement situations, a measuring instrument may consist of several seperate elements.



First, it consists of transducing elements for conversion of measurand to an analogous form. The analogous signal is then processed by some intermediate means and then fed to the end devices which presents the results of the measurement for the purpose of display and or control. These components might be contained within one or more boxes, and the boxes holding individual measurement elements might be either close together or physically seperate. Because of the modular nature of the elements within it, a measuring instrument is commonly refered to as a measurement system.

(2) ## MEASUREMENT STANDARDS :- (2)

A standard of measurement is a physical representation of a unit of measurement.

There are different types of standards of measurement.

1) International Standards
2) Primary Standards
3) Secondary Standards
4) Working Standards.

The international Standards are defined by international agreement and they represent certain units of measurement to the closest possible accuracy that production and measurement technology allow. These standards are periodically evaluated and checked by absolute measurements in terms of the fundamental units. Such standards are maintained at the International Bureau of Weights & Measures and are not available to the ordinary users of measuring instruments for the purpose of comparison or calibration.

The primary standards are maintained by National Standard Laboratories in different parts of the world. These standard represent the fundamental units and some of the derived mechanical & electrical units. They are calibrated independently by absolute measurement at each of the National Laboratories. The results of such measurements

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are compared against each other, leading to a world average figure for the primary standard. Primary standards are not available for use outside the national laboratories. Main function of primary standards is the verification and calibration of secondary standards.

Secondary standards are the basic reference standards used in industrial measurement laboratories. These standards are maintained by the particular involved industry and are checked locally against reference standards available in the area. Secondary standards available in the area are maintained as their calibration is checked by that particular industrial laboratory. Such standards are calibrated and compared against the primary standards in national standards laboratories on a periodic basis. These laboratories issue a certificate of their measured value in terms of the primary standards.

Working standards are the principle tools of a measurement laboratory. These are used to check and calibrate general laboratory instruments for accuracy and performance or to perform comparison measurements in industrial applications for eg manufacturers of electronic components such as transistors, capacitors etc make use of working standards for checking the component values being manufactured e.g a standard resistor for checking of value of resistance manufactured. Working standards (4) are periodically checked against secondary standards.

CHARACTERISTICS :-

The performance characteristics of an instrumentation system are determined by how much the system measures the desired input and how thoroughly it rejects the undesirable inputs. The system operation is defined in terms of static and dynamic characteristics. Static characteristics represents the non linear and statistical effects. Dynamic characteristics represents the dynamic behaviour of the system.

STATIC CHARACTERISTICS :-

In general, static characteristics are considered for devices which are employed to measure an unvarying process condition.

1) Instrument :-

It is a device or mechanism used for determining the value or magnitude of a quantity under measurement.

2) Measurement :-

It is a process of determining the amount, degree, or capacity by comparison with the accepted standards of the system units being used.

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3) Precision :-

It is a measure of the consistency or repeatability of measurements i.e successive readings do not differ. It is the consistency of the instrument output for a given value of input.

4) Sensitivity :-

$$= \frac{\text{change in o/p magnitude}}{\text{change in i/p magnitude}}$$ which causes it after the steady-state has been reached.   Deflection factor = (1/sensitivity)

It is a constant in a linear instrument or element. i.e sensitivity should be high.

5) Resolution :-

The least interval between two adjacent discrete details, which can be distinguished one from the other, is called the resolution.

6) Error :-

The algebraic difference between the indicated value and the true value of the measured signal.

Error = Indicated value - True Value.

7) Expected value :-

The design value i.e the expected value of the designer.

8) Uncertainty :-

It provides the range within which the true value is estimated to lie.

9) Threshold :-

If the i/p to instrument is very gradually increased from zero, there will be some minimum value below which no o/p change can be observed or detected. This minimum value defines the threshold of the instrument.

Threshold.

10) Zero Stability :-

It describes the ability of the instrument to return to zero reading after the measurand has returned to zero while other conditions remain the same.

11) Zero Error :-

It is an error of a device operating under the specified conditions of use when the i/p is at the lower range-value.

12) Span Error :-

The difference between the actual span and the ideal span is called the span error.

13.) Correction :-

Correction = True value − Indicated Value.

It is added to the indicated value so as to have the true value.

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14) Hysterisis :-

It is the time-based dependence of a system's output on present and past inputs.

The maximum seperation due to hysterisis is between upscale-going and downscale-going indications of a measured variable.

15) Dead Band :-

It is the range through which an input can be varied without initiating observable response.

16) Repeatability :-

The closeness among a no. of consecutive measurements of the o/p for the same value of i/p under the same operating conditions approaching from the same direction.

17) Deviation :-

The difference b/w the measured value and true value for a particular i/p.

18) Linearity :-

It is the closeness to which a curve approximates a straight line.

19) Independent Linearity :-

It is the maximum deviation of the calibration curve from a straight line so positioned as to minimise the maximum deviation

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20) Drift :-

It is an undesired change in the output - input relationship over a period of time.

21) Point Drift :-

It is the change in o/p over a specified period of time for a constant i/p under specified reference operating conditions.

22) Dead Time :-

It is defined as the time required by a measurement system to begin to respond to a change in the measurand.

23) Dead Zone :-

It is the largest change of i/p quantity for which there is no o/p of the instrument.

24) Accuracy :-

It refers to the degree of closeness to the true value of the quantity under measurement.

a) Point accuracy :- The accuracy of an instrument is stated for only one or more points in its range.

b) Percentage of true value :-

$$\text{Error} = \frac{\text{Measured value} - \text{True value}}{\text{True value}} \times 100$$

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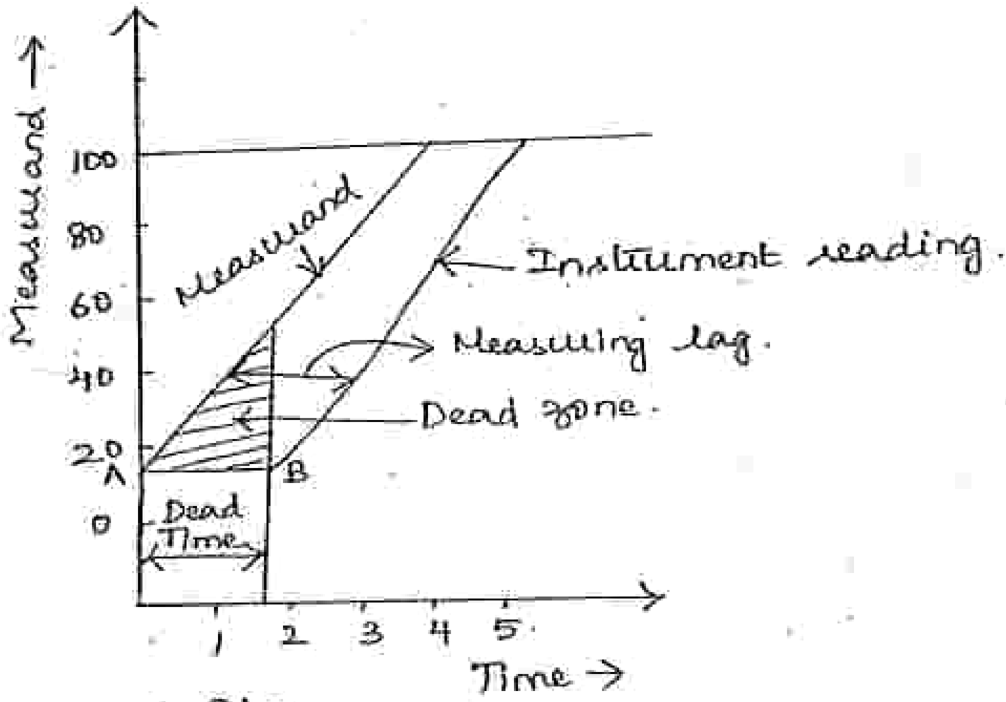
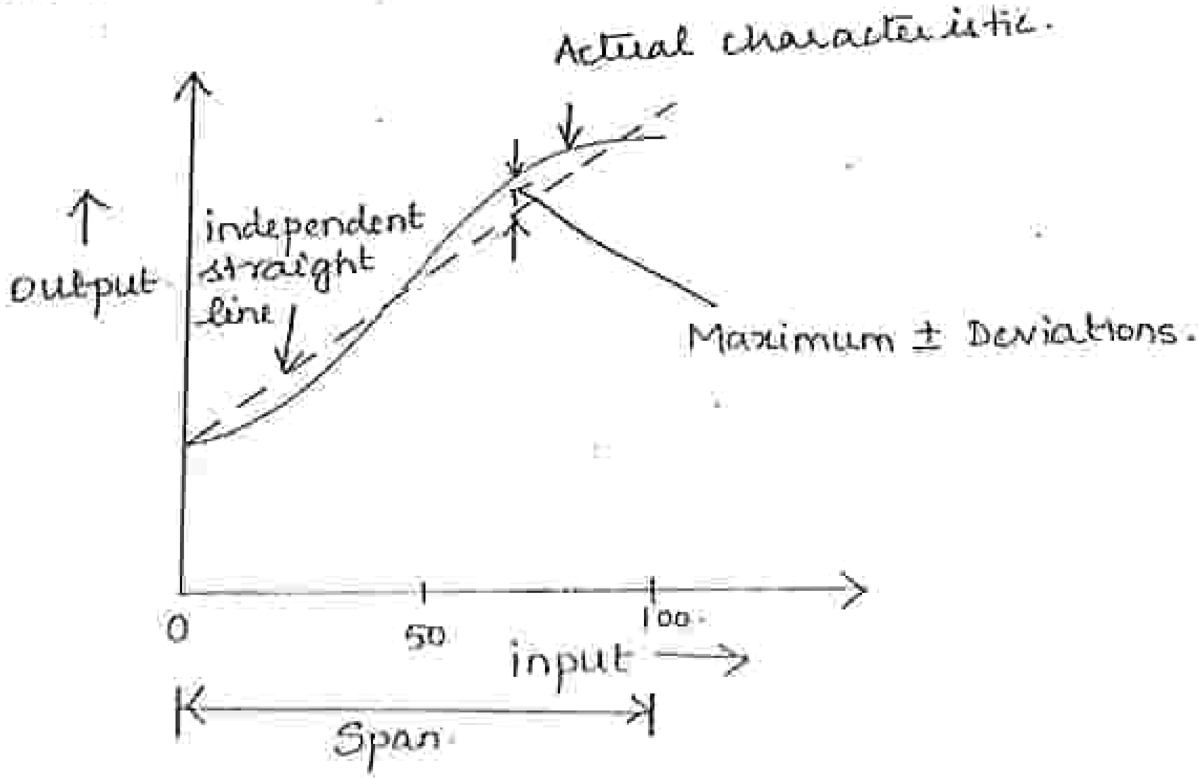
iii) Percentage of full-Scale Deflection :-

$$\text{Error} = \frac{\text{Measured value} - \text{True Value}}{\text{True scale value}} \times 100.$$



AB → Dead Time



Independent Linearity.

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Problems :-

1) A wheatstone bridge requires a change of 6Ω in the unknown arm of the bridge to produce a change in deflection of 2.4 mm of the galvanometer. Calculate the static sensitivity and deflection factor.

Soln :-

Magnitude of o/p response = 2.4 mm.

Magnitude of i/p = 6Ω.

$$\text{Static sensitivity} = \frac{\text{Magnitude of o/p response}}{\text{Magnitude of i/p}}$$

$$= \frac{2.4\text{ mm}}{6\Omega} = \underline{\underline{0.4\text{ mm}/\Omega}}$$

$$\text{Deflection factor} = \frac{1}{\text{sensitivity}}$$

$$= \frac{1}{0.4} = \underline{\underline{2.5\ \Omega/\text{mm}}}$$

2) A 5A ammeter has a resistance of 0.01Ω. Determine the η of the instrument.

Soln :-

Full scale reading $I_f = 5A$.

Ammeter resistance $R_a = 0.01\Omega$.

Power consumption for full-scale deflection

$$P_f = I_f^2 R_a$$

$$= 5^2(0.01) = 0.25\text{ W}$$

$$\eta = \frac{I_f}{P_f} = \frac{5}{0.25} = \underline{\underline{20\text{ A per watt}}}$$

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3) An ammeter has 100 divisions on its index scale and is provided with range multiplier switches 1, 10 and 100. Find the range of the instrument and scale range.

Soln

Range of instrument $= 100 \times 100$

$= 10000.$

Scale $= 0$ to $100.$

4) The dead space in a certain pyrometer is 0.12 % of span. The calibration is 500°c to 1250°c. Determine the temp. change that might occur before it is detected.

Soln

Span $= 1250 - 500 = 750°C.$

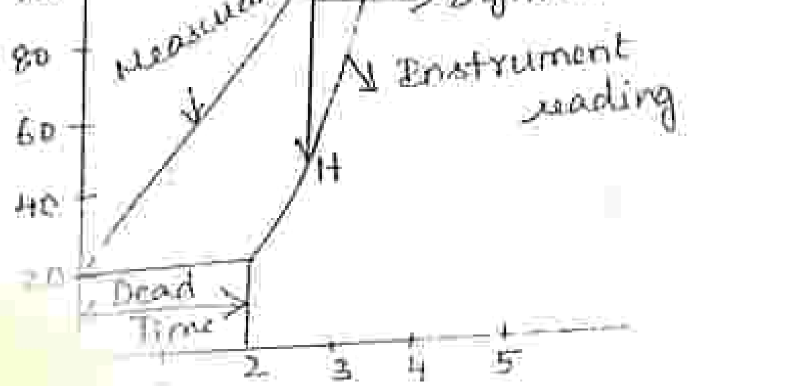
Dead space $= 0.12\%$ of span

$$= \frac{0.12}{100} \times 750 = 0.9°c.$$

DYNAMIC CHARACTERISTICS :-

i) Dynamic Error :-

It is the difference of true value of the quantity changing with time and the value indicated by the instrument provided static error is zero.



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ii) Fidelity :-

It is the ability of the system to reproduce the o/p in the same form as the i/p. Ideally a system should have 100% fidelity and the o/p should appear in the same form as the i/p and there is no distortion produced by the s/m.

iii) Bandwidth :-

Bandwidth of a system is the range of frequencies for which its dynamic sensitivity is satisfactory.

iv) Speed of Response :-

It refers to its ability to respond to sudden changes of amplitude of i/p signal.

v) Time Constant :-

It is associated with the behaviour of a first-order system.

It is defined as the time taken by the system to reach 0.632 times its final o/p signal amplitude.

vi) Measuring Lag :-

It is defined as the delay in the response of an instrument to a change in the measurand.

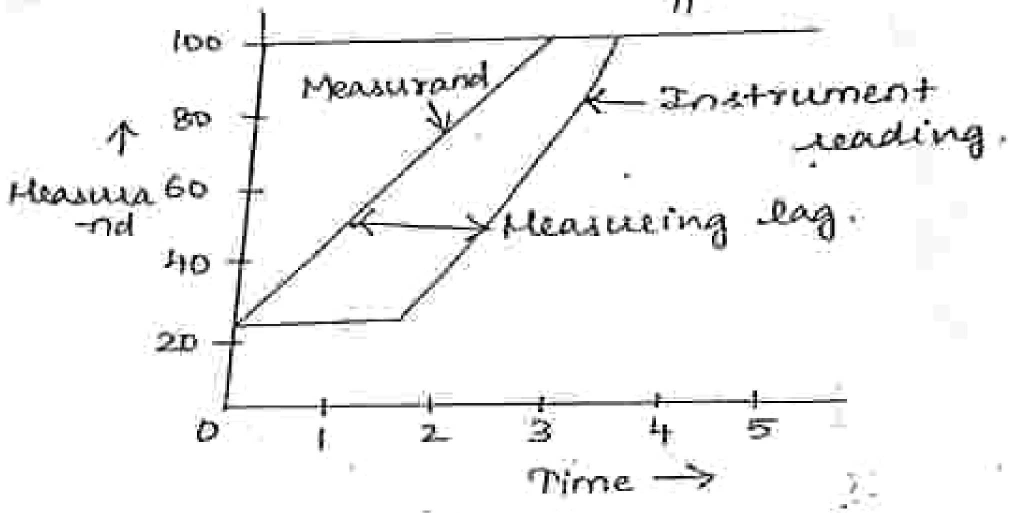
Measurement lag

Retardation type

response of the inst. begins immediately after a change in the measurand has occurred.

Time delay time.

the response of the system begins after a delay time after the application of the i/p.



vii) Settling or Response Time :-

It is the time reqd. by the instrument or measurement system to settle down to its final steady state position after the application of the i/p.

Dynamic range :-

It is the range of signals which the measuring system is likely to respond faithfully under dynamic conditions.

$$\text{Dynamic range} = \frac{\text{Amplitude of the largest signal given to the system to get satisfactory response}}{\text{Amplitude of the smallest signal given to the system to get satisfactory response}}$$

Dynamic range is usually expressed in dB.

ERRORS IN MEASUREMENT :-

(errors after measurement)

Absolute Error :-

$$\delta A = A_m - A$$

$\delta A \rightarrow$ Absolute error.

$A_m \rightarrow$ measured value.

$A \rightarrow$ True value.

Relative Error / Percentage Error :-

$$\epsilon_r = \frac{\delta A}{A}$$

Limiting or Guarantee errors :-

Manufacturers of equipments/apparatus give guarantee about the accuracy of the equipment/apparatus with some limiting deviations from the specified value in order to enable the purchaser to make proper selection according to his requirements.

The deviations from the specified values are known as limiting errors.

Errors that may enter during measurement of any quantity.

- Gross Errors.
- Random errors
- Systematic Errors
  - Instrumental errors.
  - Environmental errors.
  - Observational errors.
  - Static errors
  - Dynamic errors

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1) Gross Errors :-

- Errors because of mistakes in reading or using instruments & in recording and calculating measurement results.

- Usually because of human mistakes and these may be of any magnitude.

- Complete elimination of gross errors is not possible, but one can minimize them.

2) Systematic Errors :-

- Remain constant or change according to a definite law on repeated measurement of the given quantity.

a) Instrumental Errors :-

- Inherent in the measuring instruments because of their mechanical structure and calibration or operation of the apparatus used. For e.g.,

In ammeter or voltmeter, friction in bearings of various components may cause incorrect readings

Such errors can be avoided by,

a) Selecting a proper measuring device for the particular application.

b) applying correction factors after determining the magnitude of instrumental error.

c) Calibrating the measuring device or instrument against a standard.

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b) Environmental Errors :-

- These errors are troublesome as these changes with time in an unpredictable manner.

- These errors are introduced due to use of an instrument in different conditions than in which it was assembled and calibrated.

Eg :- Change in temperature is the major cause of errors ~~such~~ as it changes the dimensions, resistivity, spring effect and others.

c) Observational Errors :-

- These are caused by the observer.

- Most common is the parallax error introduced in reading a meter scale.

- Such errors can be minimised by providing a mirror beneath the scale.

d) Static Errors :-

- Caused due to limitations of the measuring device or the physical laws governing its behaviour.

- It is defined as the difference between the measured value & true value of a quantity

e) Dynamic Errors :-

- Caused by the instruments not responding fast enough to follow the variations in a measured variable.

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3) Random Errors :-

- Errors that remain even after systematic errors have been reduced.

- These are generally an accumulation of a large number of small effects and may be of real concern only in measurements requiring a high degree of accuracy.

CALIBRATION OF METERS :-

The calibration of all instruments is important since it affords the opportunity to check the instrument against a known standard thereby helping in evaluation of errors and accuracy.

Calibration process involves,
Comparing a particular instrument with either

1) a primary standard.
2) a secondary standard with a higher accuracy than the instrument to be calibrated
3) an instrument of known accuracy.

Actually all the working instruments which are used for measurement must be calibrated against some reference instruments which have a higher accuracy. Thus reference instruments must be calibrated against instruments of still higher grade of accuracy or against primary standards or against other standards of known accuracy.

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CLASSIFICATION OF METERS :-

- Instruments
  - Absolute & Secondary Instruments
  - Direct Measuring & Comparison Instruments.
  - Deflection & Null-type Instruments
  - Analog & Digital Instruments

1) **Absolute Instruments :-**

The instruments of this type give the magnitude of the quantity to be measured in terms of instrument constant and its deflection. They do not require any comparison with any other standard instrument. Such instruments are used in standard laboratories as standardising instruments.

Secondary Instruments :-

These instruments are so designed that the measurand can only be measured by observing the o/p indicated by the instrument. These instruments required to be calibrated by comparison with an absolute instrument.

Eg :- Ammeters, Voltmeters, Wattmeters, etc

They can be classified as,

- Indicating Instruments
- Recording Instruments
- Integrating Instruments.

Indicating Instruments :-

– Instruments indicate the magnitude of an electrical quantity at the time when its is being measured.

– Indications are given by a pointer moving over a dial.

– Eg : ammeters, voltmeters, wattmeters, etc.

Recording Instruments :-

– Instruments which keep a continuous record of the variations of the magnitude of an electrical quantity to be observed over a definite period of time. These instruments has a moving system which carries an inked pen which touches lightly a sheet of paper.

Integrating Instruments :-

Instruments which measure the total amount of either quantity of electricity or electrical energy supplied over a period of time.

eg : energy-meters.

2) Direct Measuring Instruments :-

– Converts the energy of the unknown quantity directly into energy that deflects the moving element of the instrument.

– the value of the unknown quantity being measured by reading the resulting deflection. eg Ammeters, Voltmeters, Wattmeters, etc

Comparison Instruments :- (2)

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- Measure the unknown quantity by comparing it with a standard that is often contained in the instrument case such as resistance measuring bridges.

eg:- dc and ac bridges, potentiometers.

3) Deflection Instruments :-

The quantity under measurement produces some physical effect which deflects or produces a mechanical displacement of the moving system of the instrument. An opposing effect is built in the instrument which tries to oppose the deflection or the mechanical displacement of the moving system. The opposing effect increases until a balance is achieved, at which point the deflection is measured and the value of the measurand is noted.

Null Type Instruments :-

These instruments attempts to maintain deflection at zero by applying an opposing force that is generated by the measurand. When the effect provided by measurand is not equal to the opposing effect, the instrument deflects. When both are equal, the instrument shows zero deflection.

4) Analog Instruments :-

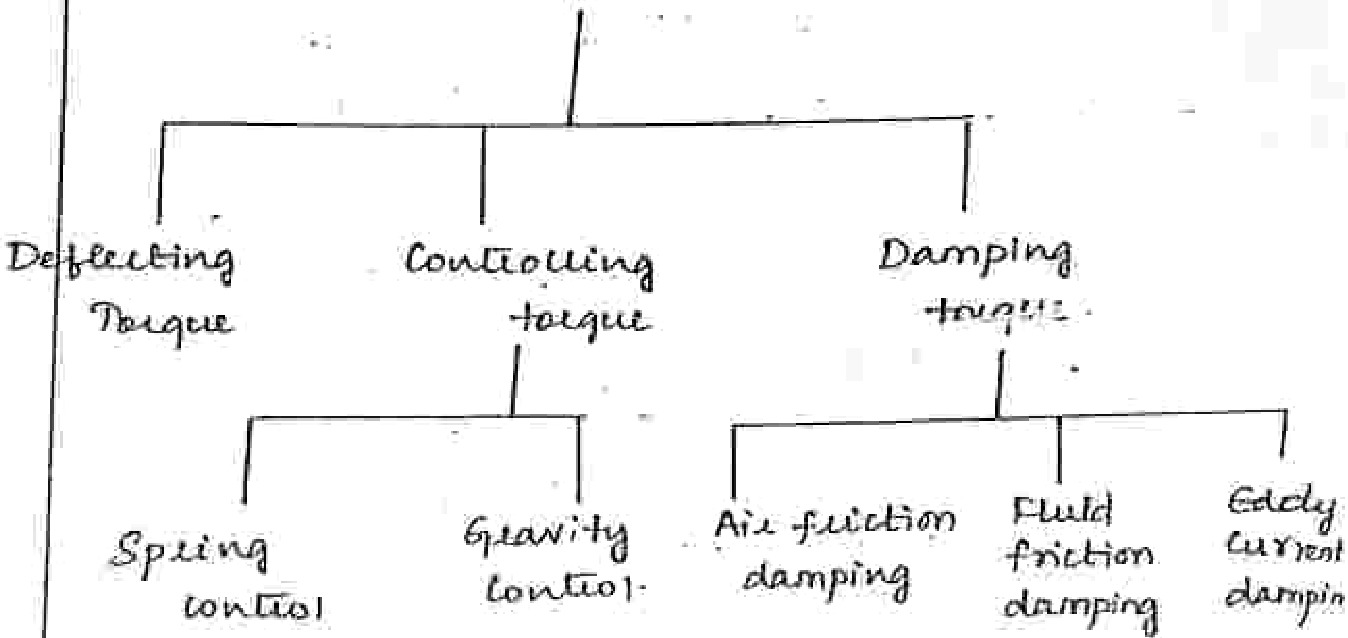
It provides an output which varies continuously as the quantity under measurement changes. The output can have an infinite no. of values within the range that the instrument is designed to measure.

Digital Instruments :-

It has an output which varies in discrete steps and so can have only finite number of values.

OPERATING FORCES :-

It can be classified as,



ESSENTIALS OF INDICATING INSTRUMENTS :-

Indicating instruments consists of a pointer moving over a calibrated scale and attached to the moving system connected on jewelled bearings. For satisfactory working of indicating instruments, the torques required are,

i) deflecting torque
ii) Controlling torque.
iii) Damping torque.

1) DEFLECTING TORQUE :-

This torque makes use of one of the magnetic, heating, chemical, electrostatic and electromagnetic induction effects of current or voltage.

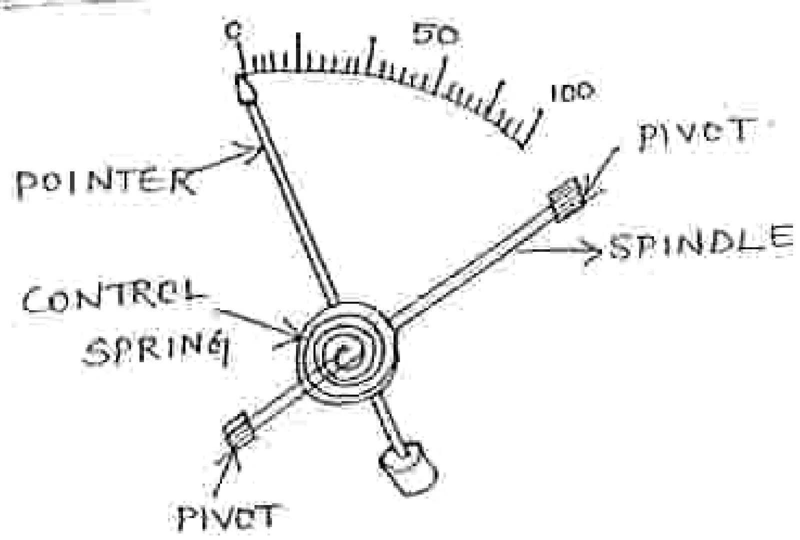
It makes the moving system of the instrument to move from its zero position when the instrument is connected in an electrical circuit to measure the electrical quantity.

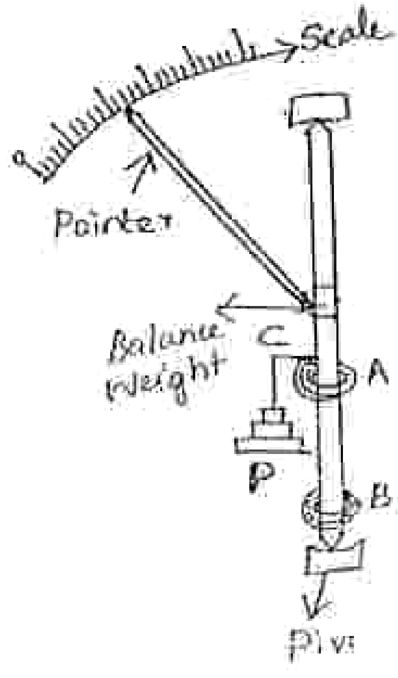
2) CONTROLLING TORQUE :-

Only if deflecting torque is present, the pointer would move indefinitely. Therefore some controlling torque is required. This torque opposes the deflecting torque and increases when the deflection of the moving system moves.

When controlling torque is present, the pointer will return to zero position when the source producing the deflecting torque is removed.

a) Spring Control :-





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– The phosphor bronze spiral hair springs A and B coiled in opposite directions and acting one against the other are used.

– One end of each spring is attached to the spindle.

– The outer end of spring A is attached to a lever at point C pivoted at point P.

– The outer end of B is fixed.

– Under the influence of deflecting torque, when the pointer moves, one of the springs unwinds it self and the other spring gets twisted.

– This twisting spring produces controlling torque.

– Controlling torque $\propto$ angle of deflection of the moving system, θ

– When deflecting torque = controlling torque, the pointer comes to rest.

$\therefore$ – $T_c \propto \theta$, $T_c = K_1 \theta$

$T_d \propto I$ $T_d = K_2 I$.

In final position, $T_c = T_d$. , $K_1 \theta = K_2 I$,

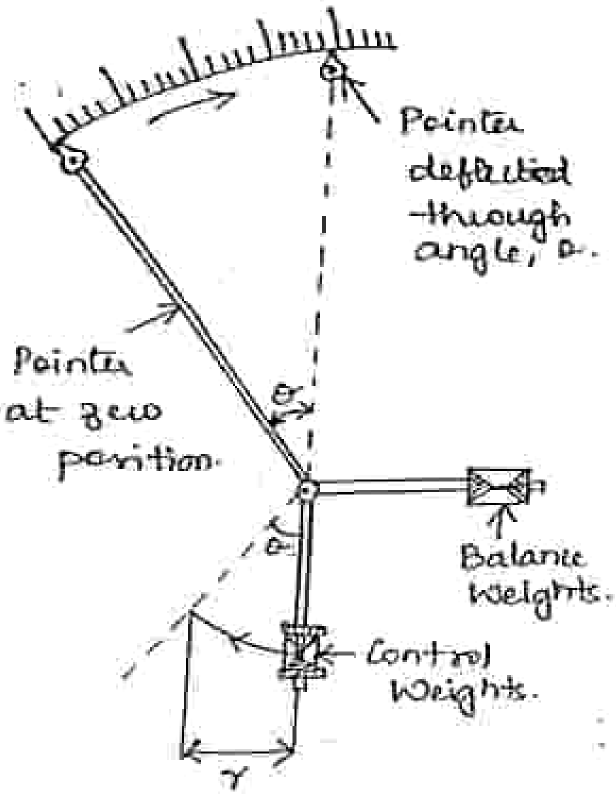
$\therefore \theta \propto I$.

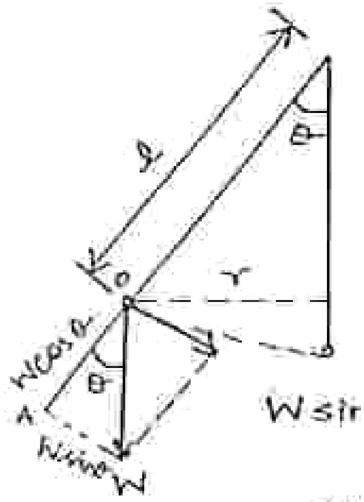
– In spring control instruments, the scale is uniform.

b) GRAVITY CONTROL :-

The temperature and ageing of the spring may affect the spring control.

So it is advantageous to substitute gravity for spring control in electrical measuring instruments.





$\cos\theta = \frac{OA}{W}$

$\sin\theta = \frac{AW}{W}$

- In gravity controlled instruments, a small weight is attached to the moving system.
- It produces a controlling torque when the moving system is in deflected position.
- The controlling torque can be varied easily by adjusting the position of the controlling weight upon the arm.
- In zero position of the pointer, the control weight is vertical.
- When the pointer is deflected through an angle θ, from its zero position, the controlling

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weight will be in a position as shown in the dotted line in fig.

- In deflecting position,

T_c = Force x displacement

$= W \sin\theta \times l$

$T_c = Wl \sin\theta$.

(or)

$T_c \propto \sin\theta$.

$T_d \propto I$, $T_d = K_1 I$.

At final deflected position,

$$T_c = T_d$$

$Wl \sin\theta = K_1 I$

$I = \left(\frac{Wl}{K_1}\right)\sin\theta$, $I = K \sin\theta$

$I \propto \sin\theta$

$\theta = \sin^{-1} \frac{I}{K}$

- Hence in gravity control instruments, the scales are not uniform but crowded at the beginning.

Disadvantage :-

- Gravity-controlled instruments must be use in vertical position in order that the control may operate

Advantage :-

- cheap
- unaffected by change in temp and free from ageing.

3) DAMPING TORQUE :-

- Damping force or torque is also necessary to avoid oscillations of the moving system about its final deflected position.
- The oscillations may be due to inertia of the moving parts and to bring the moving system to rest in its final deflected position quickly.
- If damping torque is absent, the moving system of an instrument will oscillate about the position at which $T_c = T_d$.
- The function of damping is to absorb energy from the oscillating system and to bring it to rest promptly in its equilibrium position so that its indication may be observed.
- If the instrument is underdamped, the moving system will oscillate about its final position and take some time to come to rest in its steady position.
- If the instrument is overdamped, the moving system will become slow
- If the pointer rises quickly to the deflected position, without oscillations, the damping is said to be 'critical' and the instrument is said to be 'dead beat'.

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- Hence in practice to obtain best results the damping is adjusted to the value slightly less than the critical value.

- The damping torque must operate only while the moving system of the instrument is actually moving and always oppose its motion.

Various methods of Damping :-

i) Air Friction Damping :-
ii) Fluid friction damping.
iii) Eddy current damping.

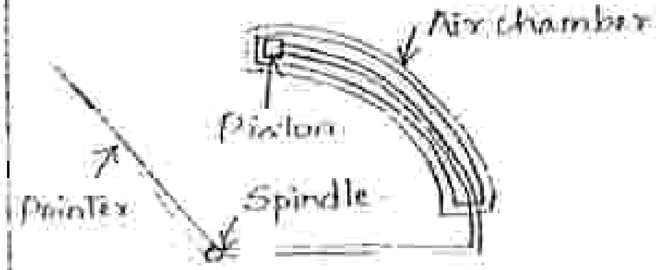
AIR FRICTION DAMPING :-

- a light aluminium piston is attached to the moving system

- the piston moves with a very small clearance in fixed air chamber closed at one end.

- If the piston is moving rapidly into the chamber, the air inside the chamber is compressed and thus the pressure inside the chamber opposes the motion of the piston.

- If the piston is moving outside, pressure inside the chamber falls and therefore the outside pressure becomes greater than the pressure inside the chamber and again the motion is opposed.



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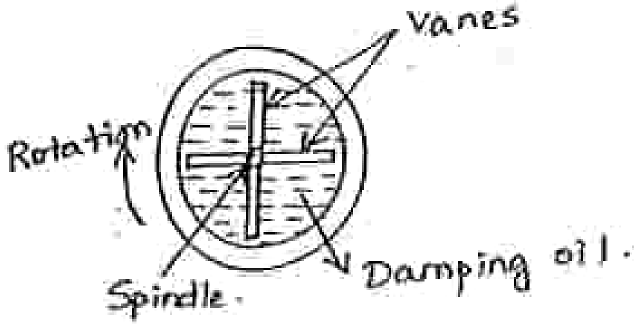
FLUID FRICTION DAMPING :-

In this method of damping, light vanes or disc are attached to the spindle of the moving system and they move in a damping oil.



EDDY CURRENT DAMPING :-

- whenever a sheet of conducting but non-magnetic material like copper or aluminium moves in a magnetic field, so as to cut through lines of force, eddy currents are set up in the sheet.
- Due to these eddy currents, a force opposing the motion of the sheet is experienced between them and the magnetic field.
- This force is proportional to the eddy currents and the strength of the magnetic field.

$F_d \propto I_e B.$

- $I_e \propto$ velocity of the moving system.

- ∴ If B is constant,

$F_d \propto$ velocity of the moving system.

$F_d = 0$, when the moving system is at rest.

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AMMETERS AND VOLTMETERS :-

Ammeters and Voltmeters operate on the same principle.

Ammeter :-

It carries the current to be measured as this current produces a deflecting torque.

It is connected in series with the circuit carrying the current under measurement.

It must be of very low resistance so that the voltage drop across the ammeter and power absorbed from the circuit are as low as possible. $P = I^2 R$ (↓ ↓)

Voltmeter :-

It is connected in parallel with the circuit across which the voltage is to be measured.

It must be of very high resistance so that the current flowing through the voltmeter and the power absorbed by the circuit are minimum as possible. $P = \frac{V^2}{R\uparrow}$ (↓)

It is dangerous to use ammeter as voltmeter and vice versa. The low resistance winding of ammeter may get damaged. However an ammeter of low range may be used as a voltmeter by connecting a high resistance in series provided the current through the series combination is within the range of the ammeter when connected across the voltage to be measured.

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MOVING COIL INSTRUMENTS :-

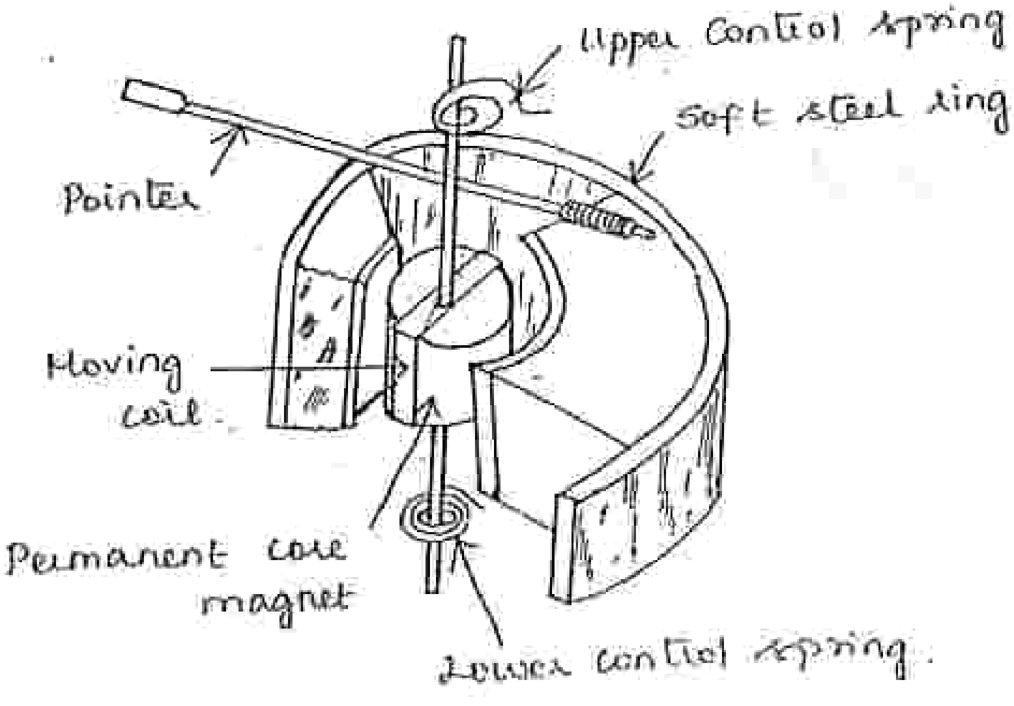
3

The permanent magnet moving coil instrument is the most accurate type for d.c measurements.

PRINCIPLE :-

An action caused by electromagnetic deflection using a coil of wire and a magnetized field when current passes through the coil, a needle is deflected. Here the direct reading instrument is provided with a pointer and a scale.

CONSTRUCTION :-



MOVING COIL :-

The moving coil is wound with many turns of copper wire. The coil is mounted on a rectangular aluminium former. The coil moves freely in the field of a permanent magnet.

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MAGNET SYSTEM :-

The flux densities used in PMMC instruments vary from 0.1 Wb/m^2 to 1 Wb/m^2. Thus in small instruments it is possible to use a small coil having small no. of turns and hence a reduction in volume is achieved. The moving coil moves over the magnet.

CONTROL :-

When the coil is supported between two jewel bearings, the control torque is provided by two phosphor bronze hair springs. These springs also serve to lead current in and out of the coil. These springs are coiled in opposite directions to get the control torque.

DAMPING SYSTEM :-

Damping torque is produced by movement of the aluminium former moving in the magnetic field of the permanent magnet.

POINTER AND SCALE :-

The pointer is carried by the spindle and moves over a graduated scale and indicates the angular deflection of the coil and therefore current flowing through the coil. The scale is uniform. In order to avoid parallax error, the scale is mounted on a raised platform and a mirror is provided beneath the pointer.

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TORQUE EQUATION :-

When the current to be measured is passed through the coil, a deflecting torque is produced on account of reaction of the permanent magnetic field with the coil magnetic field. The direction of deflecting torque can be determined by applying Fleming's left hand rule.

If i is the current in amperes flowing through the coil of turns N and length l metres and B is the flux density, then,

deflecting force, $F = BilN$ Newtons.

If r is the distance in metres between the centre of the coil, then

$$T_d = \text{Force} \times \text{distance}$$

$$T_d = F \times r$$

$$T_d = BilNr$$

If flux density B is constant, then,

$$T_d \propto i$$

Since spring control is used,

$$T_c \propto \theta$$

For G. contr.

$T_c \propto \sin$

At steady deflection position,

$$T_c = T_d$$

$$\theta \propto i$$

Since θ is directly to current, the scale markings of the dc PMMC instrument are linearly spaced.

MOVING IRON INSTRUMENTS :-

The most common ammeters and voltmeters for laboratory use are the MI instruments.

PRINCIPLE :-

A plate or vane of soft iron or of high permeability steel forms the moving element of the system. The iron vane is situated such that it can move in a magnetic field produced by a stationary coil. The coil is excited by the current or voltage under measurement. When the coil is excited, it becomes an electromagnet and the iron vane moves in such a way so as to increase the flux of the electromagnet. This is because the vane tries to occupy a position of minimum reluctance. Thus the force produced is always in such direction so as to increase the inductance of coil.

TORQUE EQUATION :-

Consider a small increment in current that is supplied to an instrument. When this happens there will be a small deflection $d\theta$, and some mechanical work will be done.

Let T_d be the deflecting torque

$\therefore$ Mechanical work done $= T_d \cdot d\theta$

Also there will be a change in the energy stored in the magnetic field due to change in inductance

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Suppose the initial current is I, the instrument inductance L and the deflection θ.

If the current increases by dI, then the inductance changes by dL and the deflection changes by $d\theta$.

If the current should be increased to dI, then the applied voltage must be increased. To increase the voltage, there must be a change in flux.

$$L = \frac{\psi}{I}$$

$$\psi = LI$$

$$e = \frac{d(\psi)}{dt}$$

$$e = \frac{d(LI)}{dt}$$

$$e = L\frac{dI}{dt} + I\frac{dL}{dt} \quad \text{——— (1)}$$

The electrical energy supplied is $e\,I\,dt$

$$= I^2 dL + IL\,dI$$

The stored energy changes from

$$\frac{1}{2} I^2 L \text{ to } \frac{1}{2}(I + dI)^2 (L + dL).$$

Hence the change in stored energy

$$= \frac{1}{2}(I + dI)^2 (L + dL) - \frac{1}{2} I^2 L$$

Neglecting the higher order terms, we get,

$$IL\,dI + \frac{1}{2} I^2 dL$$

$$e \propto \frac{di}{dt}$$

$$e = L\frac{di}{dt}$$

Energy supplied

$$E = V \times I \times dt$$

$$= L\frac{di}{dt} \times i \times dt$$

$$e = Li\,di$$

$$W = \int_0^I i\,dt$$

$$= \frac{1}{2} L I^2$$

(35)

From the principle of the conservation of energy, 8

Electrical energy supplied = Increase in stored energy + Mechanical work done.

$$I^2 dL + ILdI = ILdI + \frac{1}{2} I^2 dL + T_d \cdot d\theta.$$

$$T_d \cdot d\theta = \frac{1}{2} I^2 dL.$$

Deflecting torque $T_d = \frac{1}{2} I^2 \frac{dL}{d\theta}$.

Under balanced condition, $T_d = T_c$.

For Spring control

$$T_d = T_c.$$

$$\frac{1}{2} I^2 \frac{dL}{d\theta} = K\theta.$$

$$\theta = \frac{1}{2} \frac{I^2}{K} \frac{dL}{d\theta}.$$

For Gravity control.

$$T_d = T_c.$$

$$\frac{1}{2} I^2 \frac{dL}{d\theta} = K \cdot \sin\theta$$

$$\sin\theta = \frac{1}{2} \frac{I^2}{K} \cdot \frac{dL}{d\theta}.$$

Hence the deflection is proportional to the square of the rms value of the operating current. The deflecting torque is therefore unidirectional whatever may be the polarity of the current.

Classification :-

M.I. Instruments are of two types :

i) Attraction type.

ii) Repulsion type.

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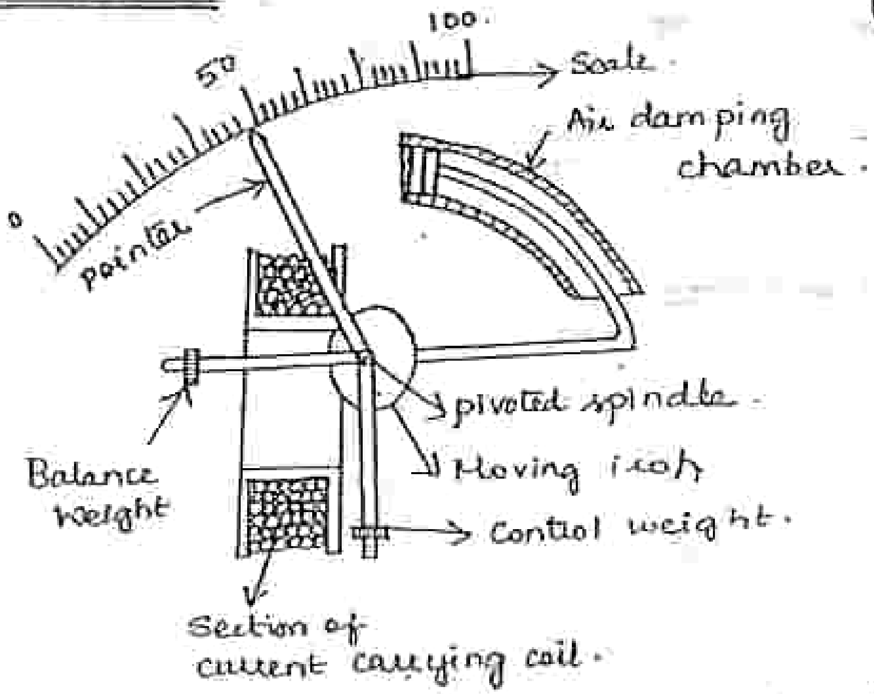
ATTRACTION TYPE :-



It uses a solenoid and moving oval shaped soft iron pivoted eccentrically. To this iron, a pointer is attached so that it may deflect along with the moving iron over a graduated scale. The moving iron is drawn into the field of solenoid when current flows through it ie when the current flows through the coil, a magnetic field is produced and the moving iron moves from the weaker field outside the coil to the stronger field inside it.

The controlling torque is provided by gravity control in case of vertically mounted instruments. Spring control can be used otherwise.

Damping is provided by air friction with the help of a light aluminium piston attached to the moving system which moves in a fixed chamber closed at one end.

REPULSION TYPE :-

In the repulsion type, there are two vanes inside the coil. One is fixed and the other movable.

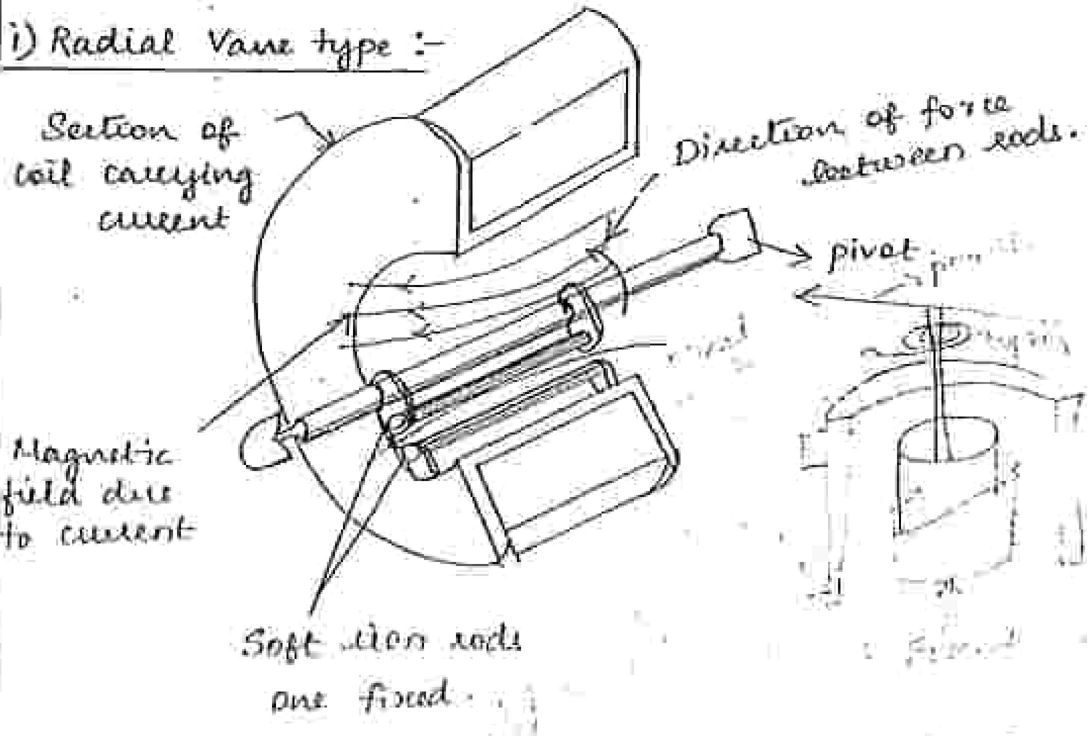
These are similarly magnetised when the current flows through the coil and there is a force of repulsion between the two vanes resulting in the movement of the moving vane.

Two different designs are in common use.

i) Radial vane type

ii) Co-axial vane type.

i) Radial Vane type :-



In this type, there are two iron rods. One fixed rod is attached to the coil and the moving rod is attached to the spindle.

The repulsion force between the two rods is proportional to the product of pole strengths

But the pole strengths of the two rods are proportional to the current flowing through the solenoid. Hence the repulsive force varies as the square of the current.

ii) COAXIAL VANE TYPE :-

It is similiar to radial type. There are two iron sheets one fixed and the other moving. This is combined with spring control.

The damping torque is provided by air friction

SHUNTS AND MULTIPLIERS :-

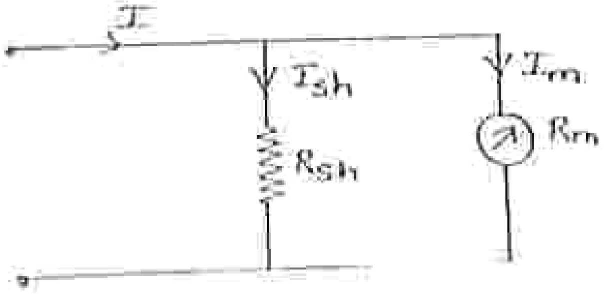
Ammeter Shunts :-

The basic movement of a d.c ammeter is a PMMC d'Arsonval galvanometer.

If the coil should carry currents greater than 100mA, the coil would become bulky and heavy.

Therefore the winding of the coil is small and light and can carry very small currents.

When heavy currents are to be measured, the major part of the current is bypassed through a low resistance called a 'shunt'



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The resistance of the shunt can be calculated using calculation.

where,

R_m → internal resistance of movement ie coil, Ω

R_{sh} → resistance of the shunt ; Ω.

I_m → full scale deflection current

I → current to be measured.

Since the shunt resistance is in parallel with the meter, the voltage drops across shunt and meter must be the same.

$$I_{sh} R_{sh} = I_m R_m.$$

$$R_{sh} = \frac{I_m R_m}{I_{sh}}$$

$$I = I_{sh} + I_m.$$

$$\therefore R_{sh} = \frac{I_m R_m}{(I - I_m)}$$

$$\frac{R_m}{R_{sh}} = \frac{I_{sh}}{I_m} = \frac{I - I_m}{I_m} = \frac{I}{I_m} - 1.$$

$$(or) \quad \frac{I}{I_m} = \frac{R_m}{R_{sh}} + 1$$

The ratio of total current to the current in the coil is called the multiplying power of shunt.

$$m = \frac{I}{I_m} = 1 + \frac{R_m}{R_{sh}}$$

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∴ Resistance of shunt

$$R_{sh} = \frac{I_m R_m}{I - I_m}$$

$$R_{sh} = \frac{R_m}{\frac{I}{I_m} - 1}$$

$$R_{sh} = \frac{R_m}{(m-1)}$$

∴ The shunt resistance used with a d' Arsonval movement may consist of a coil of resistance wire within the case of the instrument or it may be a external shunt having a very low resistance.

CONSTRUCTION OF SHUNT :-

The general requirement for shunts are :

i) the temperature co-efficient of shunt and instrument should be low and should be as equal as possible.

ii) the resistance of shunts should not vary with time.

iii) they should carry the current without excessive temp. rise.

iv) they should have low thermal electromotive force with copper.

In general Manganin is used for dc instrument + Constantan is used for ac instruments.

Voltmeter Multipliers:-

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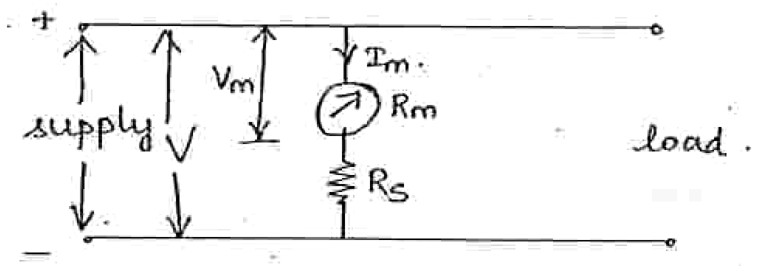
A d'Arsonval basic meter movement is converted into a voltmeter by connecting a series resistance with it. This series resistance is known as a multiplier.

The combination of meter movement and the multiplier is put across the circuit whose voltage is to be measured.



The multiplier limits the current through the meter so that it does not exceed the value for full scale deflection and thus prevents the coil from getting damaged.

Let

I_m → full scale current reading of meter.

R_m → internal resistance of meter coil.

R_s → multiplier resistance.

V_m → voltage across the meter movement for current I_m.

V → full range voltage of instrument.

(42)

From the fig.,

$$V_m = I_m R_m.$$

$$V = I_m (R_m + R_s).$$

$$R_s = \frac{V - I_m R_m}{I_m} = \frac{V}{I_m} - R_m.$$

Multiplication factor for multiplier.

$$m = \frac{V}{V_m} = \frac{I_m (R_m + R_s)}{I_m R_m} = 1 + \frac{R_s}{R_m}.$$

$$R_s = (m-1) R_m.$$

CONSTRUCTION OF MULTIPLIERS :-

The essential requirements of multipliers are :

i) their resistance should not change with time.

ii) the change in their resistance with temperature should be small.

iii) they should be non-inductively wound for a.c meters.

The resistance materials used for multiplier are manganin & constantan.

EXTENSION OF RANGE :-

Shunts are used for extension of range of ammeter and Multipliers are used for extension of range for voltmeter

The following devices may be used for extending the range of instruments.

1) Shunts
2) Multipliers
3) Current transformers.
4) Potential transformers.

Drawbacks of Shunts :-

i) It is difficult to achieve accuracy with a shunt on ac.

ii) the power consumed by shunts would be large for large currents.

iii) insulation of shunt and meter is difficult.

Drawbacks of Multipliers :-

i) its use is impractical at voltages above 1000V.

ii) Above 1000V, the power consumed by multiplier is large.

iii) Insulation for high range is difficult.

To overcome these disadvantages, instrument transformers are used.

Instrument Transformers

- Current transformer (CT)
- Potential Transformer (PT)

Current Transformer is used whenever the current of an ac circuit exceeds the safe current of the measuring instrument.

Potential transformer are used wherever the voltage of an ac circuit exceeds the voltage of 750V as it is not easy to provide insulation for voltmeters above 750V.

Advantages :-

i) Enables a single range instrument to cover a large current or voltage range.

ii) The measuring instruments can be located far away from the high voltage circuit by using long leads. Hence the measuring instruments need not be insulated.

iii) When instrument transformers are used along with measuring instruments, their readings do not depend on R, L & C constants.

iv) Several instruments can be operated from a single instrument transformer.

v) CT can be used to measure heavy current (also in a bus bar).

vi) Power loss is small.

Disadvantage :-

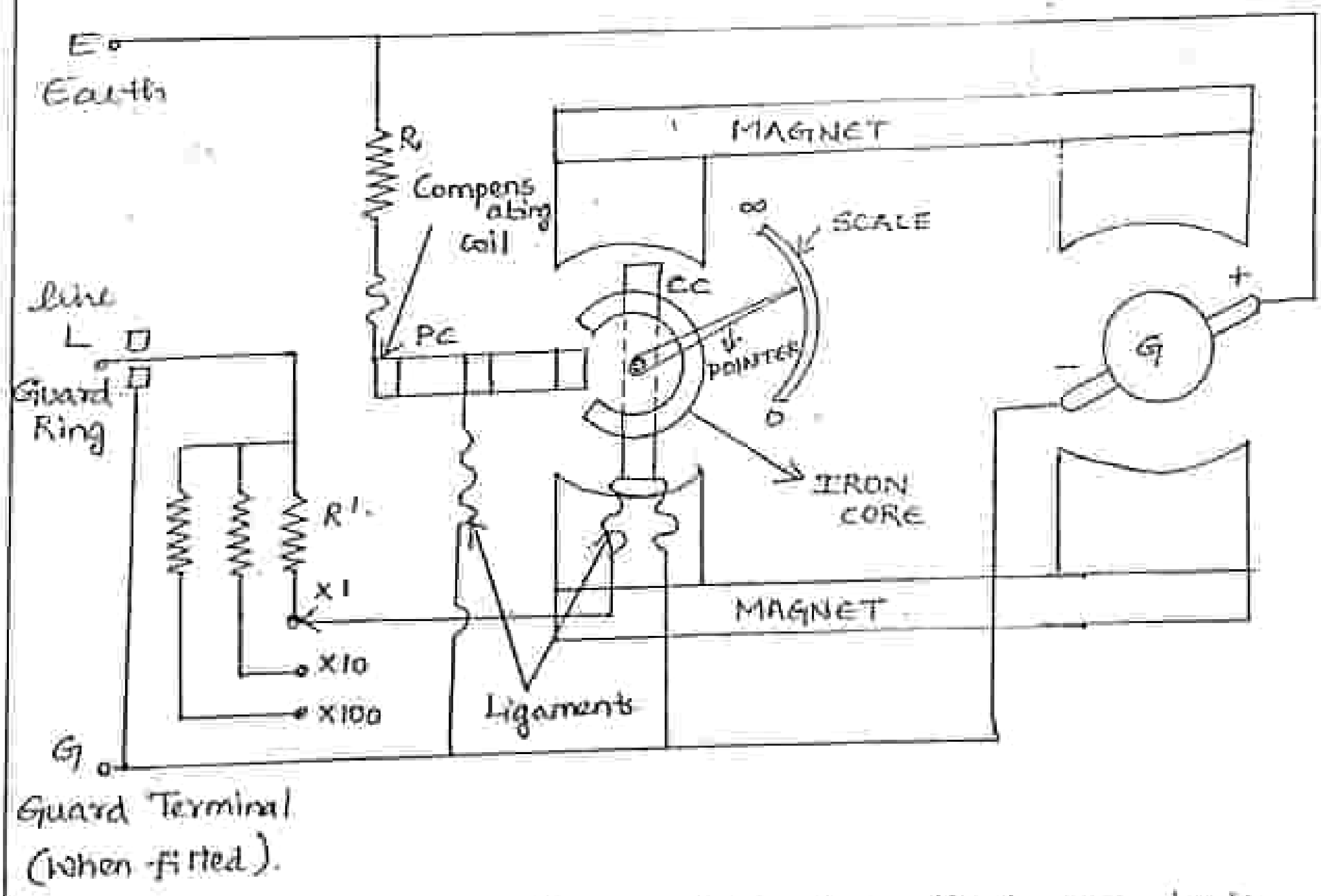
i) The instrument transformer cannot be used for d.c.

MODULE - 2

MEASUREMENT OF RESISTANCE

MEASUREMENT OF INSULATION RESISTANCE :-

Megger is an instrument used for the measurement of high resistance and insulation resistance. The megger insulation tester consists of a hand-driven dc generator and a direct reading ohmmeter.



* Permanent magnets provide the field for both the generator and the ohm-meter. The moving element of the ohm-meter consists of three coils.

i) Current coil / deflecting coil.
ii) Pressure coil / Control coil.
iii) Compensating coil.

These 3 coils are mounted rigidly to a pivoted central shaft. They are free to rotate over a stationary C-shaped iron core.

The coils are connected to the circuit by means of flexible leads called ligaments. These gives no restoring torque on the moving element. Hence the moving element may take any position over the scale when the generator handle is stationary.

The current coil is in series with the resistance R'. The series resistance R' protects the current coil in case the test terminals are short-circuited and also controls the range of the instrument. The pressure coil is in series with a compensating coil and protection resistance R is connected across the generator terminals.

The resistance under test is connected between the terminals L and E.

WORKING :-

The resistance is connected between the terminals L and E. The generator handle is then steadily turned at uniform speed. When the current from the generator flows through the pressure coil, the coil tends to set itself at right angles to the field of the permanent magnet. When the test terminals are open (it means infinite resistance) no current flows through the deflecting coil. The pressure coil thus governs the motion of the moving element, causing it to move to its extreme counter-clockwise position ie to infinite position on scale

Signature of Invigilator

Current coil is wound to produce clockwise torque on the moving element. When the test terminals L and E are short circuited, which corresponds to zero external resistance, the current flowing through the current coil is large enough to produce enough torque to overcome the counter-clockwise torque of pressure coil. This moves the pointer to extreme clockwise position ie zero on the scale.

When a resistance under test is connected between the test terminals L and E, the opposing torques of the coils balance each other so that the pointer comes to rest at some point on the scale. The scale is calibrated in mega-ohms and thousands of ohms so that the pointer indicates directly the value of resistance under test

The guard ring is provided to pass the leakage current over the test terminals to the -ve terminal of the generator without passing through the current coil. Hence the errors due to it are eliminated. The guard terminal is provided by means of which this guard ring may be connected to a guard wire on the insulation under test

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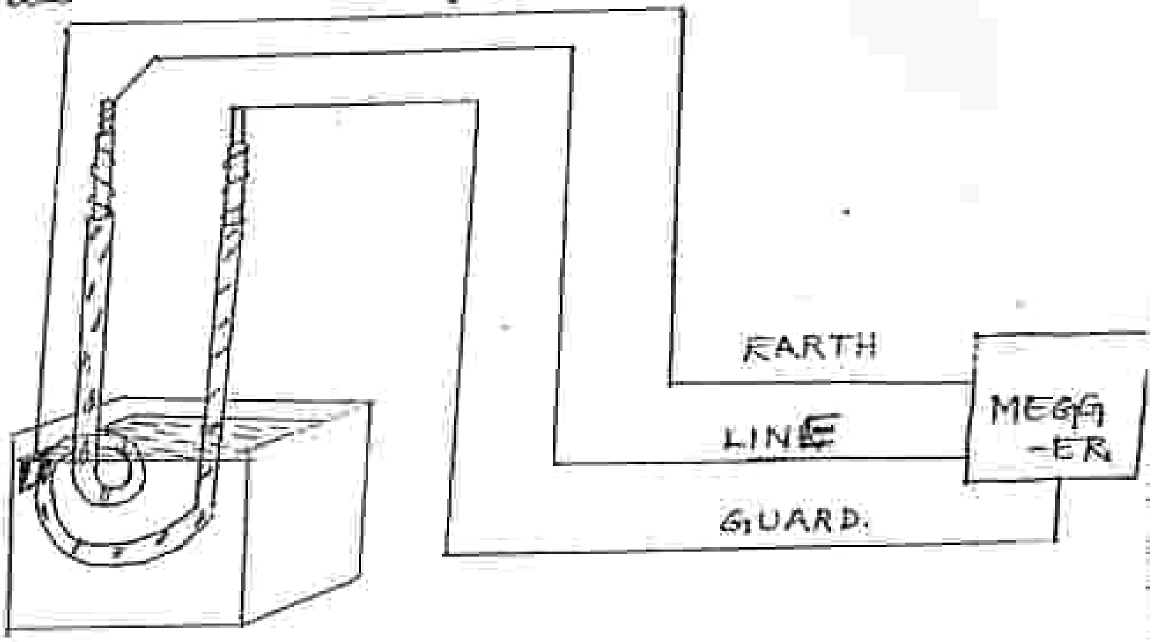
The insulation resistance of a cab may be measured by a megger.

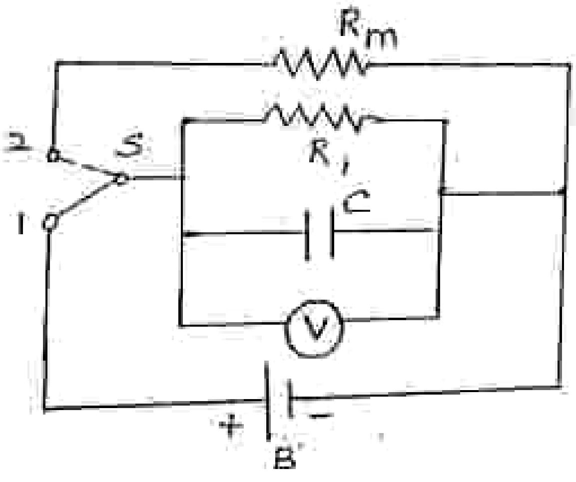


Megger is provided with 3 terminals. Line, earth and guard terminals. The line terminal is connected to the core of the cable. The earth terminal is connected to a plate immersed in the water. The guard terminal is connected tightly round the insulation.

Rotating the handle at steady speed indicates the value of insulation resistance of the cable by the final position taken up by the instrument pointer on the scale.

When the instrument handle is rotated with steady speed, voltage is generated and the current flows to charge the condenser. After several seconds charging current stops & flow and conduction current makes the pointer to move to indicate correct value of insulation resistance.

LOSS OF CHARGE METHOD :-



In this circuit,

C → capacitor of known capacitance.

V → electrostatic voltmeter.

R_1 → total leakage resistance of the capacitor and voltmeter.

R_m → Resistance to be measured,

In this method, the capacitor is first charged by means of a battery to some voltage by by putting switch S on terminal 1 and then allowed to discharge through the resistance $R_m + R_1$ by putting switch S on terminal 2. The time taken t for the potential difference to fall from V_1 to V_2 during discharge is observed by a stopwatch.

Let the equivalent resistance of R_1 and R_m connected in parallel be R'

$$\frac{1}{R'} = \frac{1}{R_m} + \frac{1}{R_1}.$$

(55) If at any instant the voltage on the discharging capacitor is v volts, the charge on the discharging capacitor is q coulombs and the capacity of the capacitor is C farads, then

<u>CASE 1</u> :- To find the value of total resist R'

$$i = \frac{-dq}{dt} = -C\frac{dv}{dt} \quad \text{——— (1)}$$

$$i = \frac{v}{R'} \quad \text{——— (2)}$$

$$\frac{v}{R'} = -C\frac{dv}{dt}$$

$$\frac{dv}{v} = \frac{-dt}{CR'}$$

Integrating both sides for limits of v from V_1 to V_2 and for time from 0 to t,

$$\int_{V_1}^{V_2} \frac{dv}{v} = \int_0^t \frac{-dt}{CR'}$$

$$\left[\log_e v\right]_{V_1}^{V_2} = \left[\frac{-t}{CR'}\right]_0^t$$

$$\log_e \frac{V_2}{V_1} = \frac{-t}{CR'}$$

$$\boxed{V_2 = V_1 e^{-t/CR'}}$$

From the above expression, the value of R' can be determined.

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The test is then repeated with unknown resistance R_m disconnected, the capacitor being discharged through R_1 only. Thus the value of R_1 can also be found out by $V_2 = V_1 e^{-t/CR_1}$.

$$\therefore \frac{1}{R_1'} = \frac{1}{R_m} + \frac{1}{R_1}.$$

Hence, the value of R_m can be found out by,

$$\frac{1}{R_m} = \frac{1}{R_1'} - \frac{1}{R_1}$$

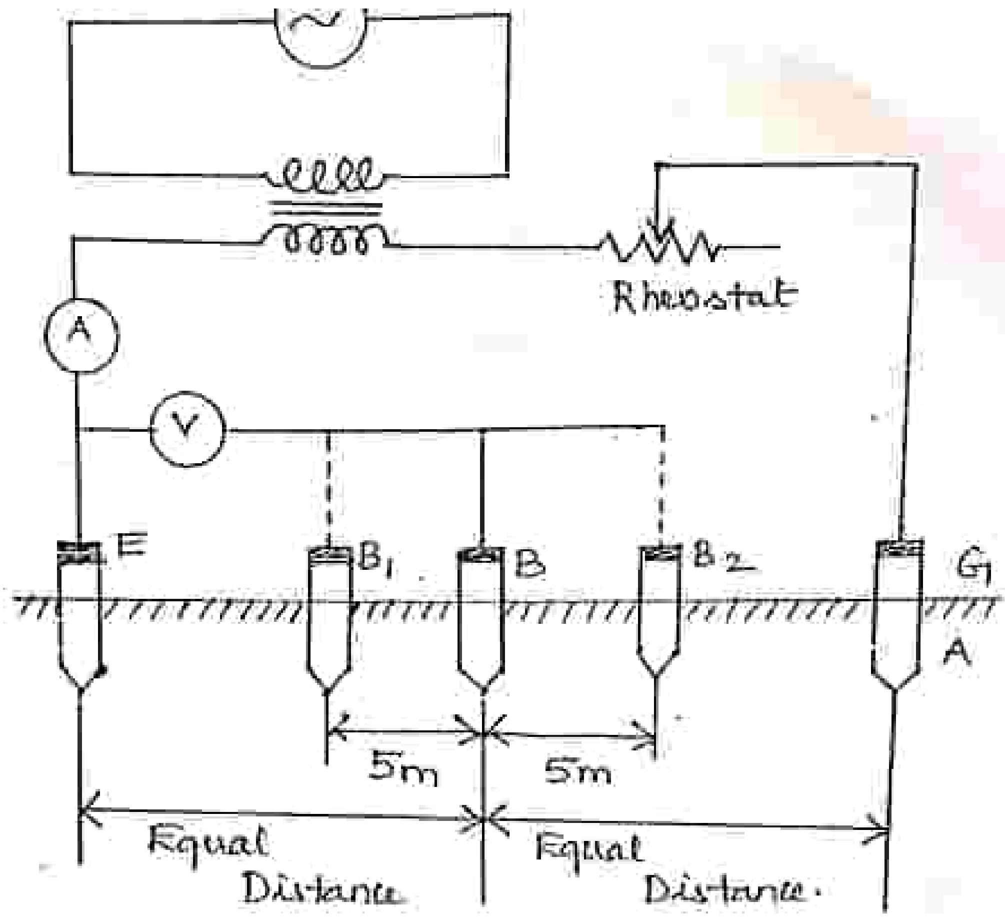
To measure insulation resistance of the cable or to measure capacitance, the test need not be repeated. In this case, connected the unknown capacitor in place of C and connect Rinknown in place of R_1. The insulation resistance in place of R_1. The value of R_1 can be obtained by the exp.

$$V_2 = V_1 e^{-t/CR_1}.$$

MEASUREMENT OF EARTH RESISTANCE :-

The determination of resistance between the earthing plate and the distribution systems is of utmost importance. This measurement is made by the potential fall method.

The resistance area of an earth electrode is the area of soil around the electrode within which a voltage gradient measurable with commercial instrument exists.



E is the earth electrode under test, and A is the auxiliary earth electrode positioned so that two resistance areas do not overlap.

B is the second auxiliary electrode placed half way between E and A.

An alternating current of steady value is passed through the earth path from E to A and the voltage drop between E and B is measured.

Then,

$$\text{Earth resistance, } R_e = \frac{\text{Voltage drop between E and B}}{\text{Current through earth path}}$$

To ensure that the resistance areas do not overlap, the auxiliary electrode B is moved to positions B_1 and B_2 respy. If the resistance value

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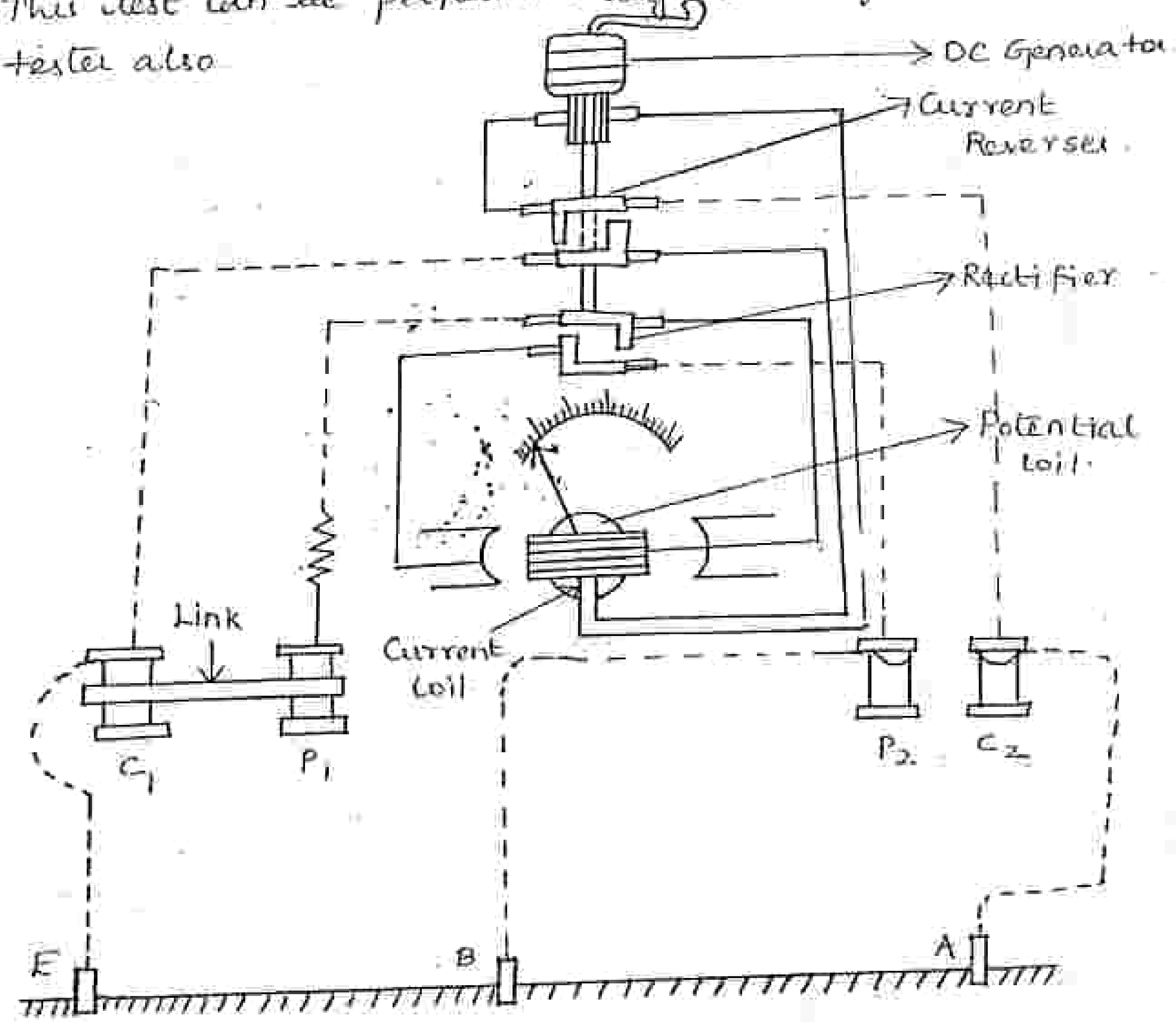
determined are of approximately the same value in all three cases, the mean of the three readings can be taken as the earth resistance of earth electrode. Otherwise, the auxiliary earth electrode A must be driven in at a point further away from E and the above test is repeated until a group of 3 readings obtained are approximately same.

The use of alternating current source is necessary to eliminate electrolytic effect.

This test can be performed by means of an earth tester also



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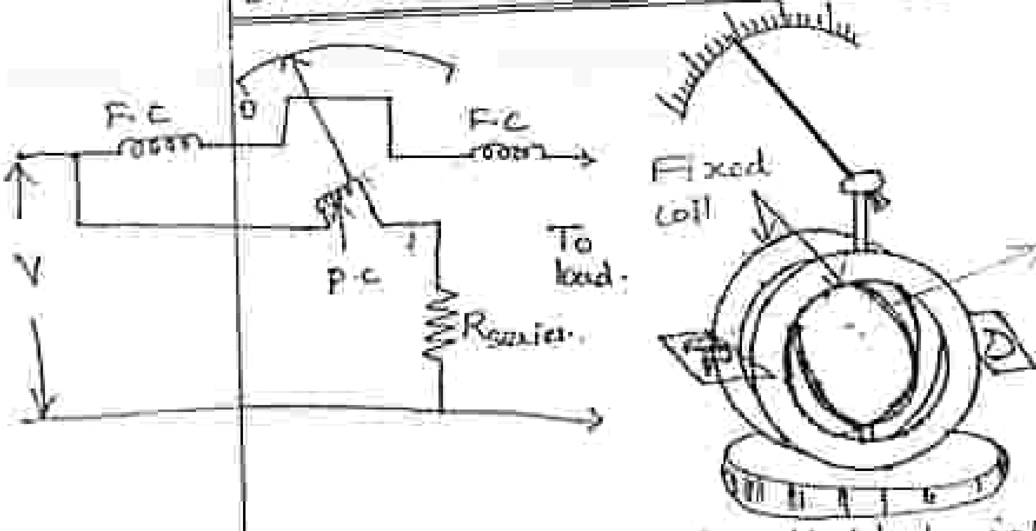
The earth tester is a special type of megger which sends ac through earth and dc through the measuring instrument. It has got four terminals. P_1, C_1, P_2 & C_2 are shorted outside. Two terminals P_1 and C_1 are shorted to form a common point which is connected to the earth electrode under test. The other two terminals C_2 and P_2 are connected to the auxiliary electrodes A and B respectively. The value of the earth resistance is indicated by the instrument directly when its handle is turned at uniform speed.

MEASUREMENT OF POWER & ENERGY.

DYNAMOMETER TYPE WATTMETER :-



* The fixed coil is divided into two equal portion in order to provide uniform field. It acts as the current coil.
* The moving coil is used as the pressure coil
* The fixed coil carries the current flowing through the circuit. $I_f = I$.

* The moving coil carries the current proportional to the voltage across the circuit. $I_m = \frac{V}{R}$.

* A high non-inductive resistance is connected in series with the moving coil in order to limit the current in it.

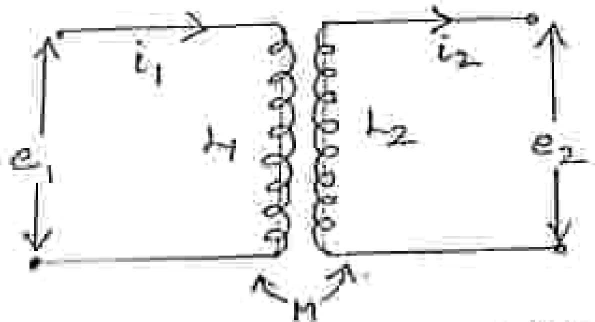
* The magnetic fields of the fixed and moving coils react on one another causing the moving coil to turn about its axis (when a current carrying coil is placed in a magnetic field, it experiences a torque).

* The movement is controlled by hair springs which leads the current into and out of the moving element.

* Damping is provided by light aluminium vanes moving in an air dashpot.

* The pointer is fixed to the moving coil and moves over a scale.

<u>TORQUE EQUATION:-</u>



Let $i_1 \rightarrow$ instantaneous value of current in the fixed coils, Amp.

$i_2 \rightarrow$ instantaneous value of current in the movable coil, Amp.

$L_1, L_2 \rightarrow$ self inductance of fixed + moving coils, Henry

$M \rightarrow$ mutual inductance between the coils. Henry

(5b)

Flux linkages of coil 1, + coil 2,

$$\psi_1 = L_1 i_1 + M i_2$$

$$\psi_2 = L_2 i_2 + M i_1 .$$

$e = V$

$e_1 = \frac{d\psi_1}{dt}$

$e_2 = \frac{d\psi_2}{dt}$

Electrical i/p energy,

$$= e_1 i_1 dt + e_2 i_2 dt$$

$$= i_1 d\psi_1 + i_2 d\psi_2 .$$

$$= i_1 d(L_1 i_1 + M i_2) + i_2 d(L_2 i_2 + M i_1).$$

$$= i_1 L_1 di_1 + i_1^2 dL_1 + i_1 i_2 dM + i_1 M di_2 + i_2 L_2 di_2 + i_2^2 dL_2 + i_1 i_2 dM + i_2 M di_1 \quad \text{--- (1)}$$

Energy stored in magnetic field,

$$= \frac{1}{2} i_1^2 L_1 + \frac{1}{2} i_2^2 L_2 + i_1 i_2 M .$$

change in energy stored,

$$= d\left(\frac{1}{2} i_1^2 L_1 + \frac{1}{2} i_2^2 L_2 + i_1 i_2 M\right)$$

$$= i_1 L_1 di_1 + \left(\frac{i_1^2}{2}\right) dL_1 + i_2 L_2 di_2 + \left(\frac{i_2^2}{2}\right) dL_2$$

$$i_1 M di_2 + i_2 M di_1 + i_1 i_2 dM \quad \text{--- (2)}.$$

From principle of conservation of energy,

Total electrical i/p energy = Change in energy stored + Mechanical energy.

Mechanical energy = (1) − (2)

$$= \frac{1}{2} i_1^2 dL_1 + \frac{1}{2} i_2^2 dL_2 + i_1 i_2 dM .$$

Self inductances L_1 & L_2 are constants

$\therefore dL_1$ & $dL_2 = 0$.

Hence Mechanical energy $= i_1 i_2 \, dM$

If T_i is the instantaneous deflecting torque, & $d\theta$ is the change in deflection,

then,

Mechanical energy = work done.

$$i_1 i_2 \, dM = T_i \, d\theta$$

$$T_i = i_1 i_2 \frac{dM}{d\theta}.$$

Operating with dc,

For spring control,

$$T_c = K\theta.$$

At final steady state position,

$$T_d = T_c$$

$$i_1 i_2 \frac{dM}{d\theta} = K\theta.$$

$$\theta = \frac{i_1 i_2}{K} \frac{dM}{d\theta}$$

$$\theta = \frac{I_f I_m}{K} \frac{dM}{d\theta}$$

Operating with ac :-

Average deflection torque over a one cycle,

$$T_d = \frac{1}{T}\int_0^T T_i \cdot dt$$

$$= \frac{1}{T}\int_0^T i_1 i_2 \frac{dM}{d\theta} \cdot dt.$$

If i_1 & i_2 are sinusoidal and are displaced by a phase angle ϕ i.e,

$$i_1 = i_f \sin\theta$$

$$i_2 = i_m \sin(\theta - \phi) \quad = i_m \cos\phi$$

$$T_d = \frac{1}{2\pi}\int_0^{2\pi} i_f \sin\theta \cdot i_m \sin(\theta-\phi) \cdot d\theta$$

$$= \left(\frac{i_f i_m}{2}\right)\left[\cos\phi\right]\frac{dM}{d\theta}$$

$$T_d = \frac{i_f}{\sqrt{2}}\frac{i_m}{\sqrt{2}}\cos\phi \frac{dM}{d\theta}$$

$$T_d = I_f I_m \cos\phi \frac{dM}{d\theta}$$

$$T_c = K\theta$$

At final steady state position,

$$T_d = T_c$$

$$\theta = \frac{I_f I_m}{K}\cos\phi \frac{dM}{d\theta}.$$

Reference

$$\int_0^{2\pi}\frac{\cos\phi - \cos(2\theta-\phi)}{2} d\theta$$

$$\frac{1}{2}\left[\theta \cdot \cos\theta - \frac{\sin(2\theta-\phi)}{2}\right]_0^{2\pi}$$

$2\pi \cos\phi$

$$\sin\theta \cdot \sin(\theta-\phi)$$

$$\frac{1}{2}\left[2\sin\theta \cdot \sin(\theta-\phi)\right]$$

$$2\sin A \sin B = \cos[A-B] - \cos(A+B)$$

$$\frac{1}{2}\left[\cos\phi - \cos(2\theta-\phi)\right]$$

$$\theta = \frac{I}{K} \cdot \frac{V}{R} \cdot \cos\phi \frac{dM}{d\theta}.$$

$$\theta = \frac{1}{KR} \cdot \frac{dM}{d\theta} (VI\cos\phi)$$

$$\boxed{\theta = \frac{dM}{KR\,d\theta} \times P.}$$

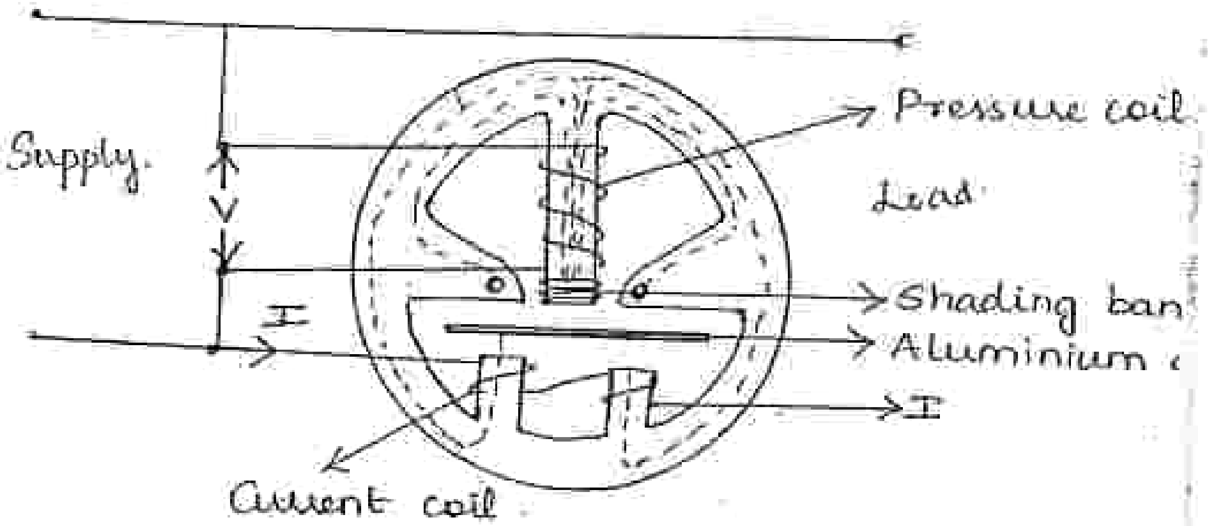
∴ Deflection is directly proportional to the power being measured.

Types of Dynamometer type Wattmeters

1) Suspended coil Torsion head dynamometer wattmeter

2) Pivoted coil, direct indicating dynamometer wattmeters.

SINGLE PHASE INDUCTION TYPE ENERGY METERS :-



CONSTRUCTION :-

FOUR MAIN PARTS :-

1) Driving System
2) Moving System
3) Braking System
4) Registering System.

Driving System :-

* Consists of 2 electro-magnets.
* The coil of one electromagnet is excited by the load current. This coil is called the current coil.
* The coil of the second electromagnet is connected across the supply and therefore carries a current proportional to the supply voltage. This coil is called the pressure coil.

* The 2 magnets are called series and shunt magnets respectively.

* Copper bands are provided on the central limb.

* The function of these bands is to bring the flux produced by the shunt magnet exactly in quadrature with the applied voltage.

MOVING SYSTEM:-

* Consists of an aluminium disc.

* The disc is positioned in the air gap between the series and shunt magnets.

* The disc is fixed to the shaft

BRAKING SYSTEM:-

* A permanent magnet near the edge of the aluminium disc forms the braking system.

* The aluminium disc moves in the field of this magnet and thus provides a braking torque.

* The position of the permanent magnet is adjustable and thus braking torque can be adjusted.

REGISTERING SYSTEM:-

* This system records continuously a number which is proportional to the revolutions made by the braking system.

OPERATION :-

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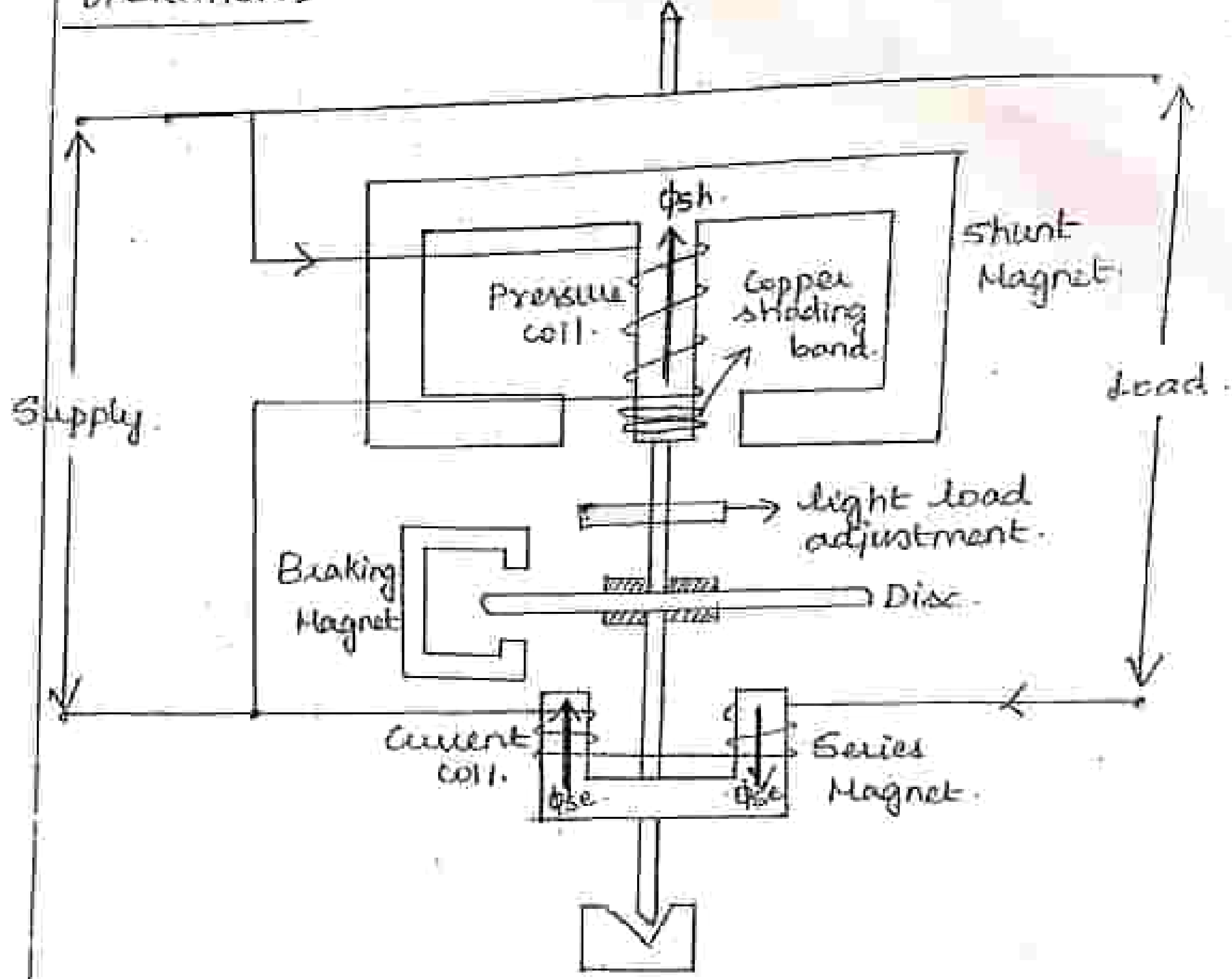

* The flux produced by the pressure coil (ϕ_{sh}) is made to lag behind the applied voltage (V) by 90°, by adjusting the position of shading bands.

* $\phi_{sh} \propto V$.

* The flux produced by the current coil (ϕ_{se} is proportional and in phase with load current (I).

* ϕ_{sh} induces emf E_{sh}, so E_{sh} produces eddy currents <u>in the disc</u> I_{esh}.

* The two fluxes ϕ_{se} induces emfs E_{se}. E_{se} produces two eddy currents I_{es}.

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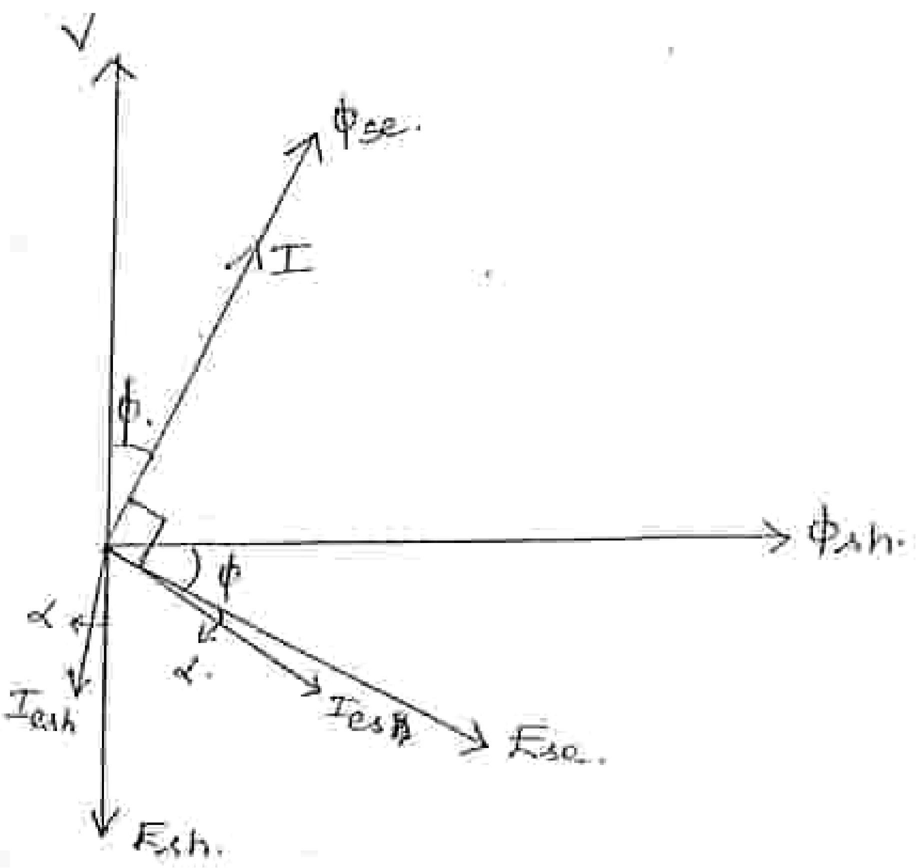
$\phi_{sh} \rightarrow E_{sh} \rightarrow I_{esh}$.

$\phi_{se} \rightarrow E_{se} \rightarrow I_{es}$.

Now, ϕ_{sh} interacts with I_{es} to produce torque.

ϕ_{pse} interacts with I_{esh} to produce torque.

These two torques are opposite in direction and hence the net torque is the difference of these.



α is very small.

Hence taking ϕ equation, by neglecting α.

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Average torque $\propto \left[\phi_{sh} \, I_{es} \cos\phi - \phi_{se} \, I_{esh} \cos(1\ldots\right.$

$$T_d \propto \left[\phi_{sh} \, I_{es} \cos\phi + \phi_{se} \, I_{esh} \cos\phi\right]$$

$\phi_{sh} \propto V, \quad I_{es} \propto I, \quad \phi_{se} \propto I, \quad I_{esh} \propto V.$

$$\phi_{sh} \, I_{es} \propto VI.$$

$$\phi_{sh} \, I_{es} = k_1 VI.$$

$$\phi_{se} \, I_{esh} \propto VI.$$

$$\phi_{se} \, I_{esh} = k_2 VI.$$

$$T_d \propto \left[k_1 VI \cos\phi + k_2 VI \cos\phi\right].$$

$$T_d \propto \left[k_1 + k_2\right] VI \cos\phi.$$

$T_d \propto VI\cos\phi \propto$ True power of the circuit.

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The braking torque is due to eddy currents induced in the aluminium disc. Since the magnitude of eddy currents is proportional to the speed of the disc, T_b is also $\propto$ speed N.

For steady speed of rotation,

$$T_b = T_d.$$

$$N = [K_1 + k_2] VI \cos\phi$$

$$N \propto \text{power}.$$

In a gn. period of time,

Total No. of revolutions $\propto$ electrical energy consumed.

$$\int_0^t N \cdot dt \propto \int_0^t P \cdot dt.$$

$$\int_0^t N \cdot dt = \int_0^t [K_1 + k_2] VI \cos\phi \cdot dt.$$

$$= K \int_0^t VI \cos\phi \, dt$$

$$= K \int_0^t \text{power} \cdot dt.$$

$$N. = K. \text{energy}.$$

$k \rightarrow$ meter constant.

$$K = \frac{N}{\text{Energy}} = \frac{\text{No. of revolutions}}{\text{KWh}}.$$

Hence the no. of revolutions made by the aluminium disc for 1KWh of energy consumption is called meter constant.

1-ϕ POWER MEASUREMENT :-

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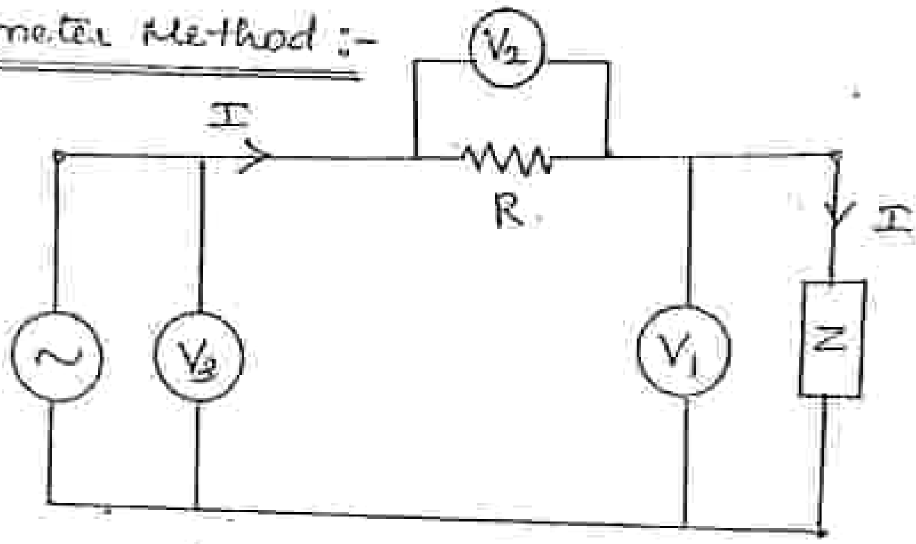
1) 3- Voltmeter Method.
2) 3- Ammeter Method.
3) Using Instrument Transformer.

3 Voltmeter Method :-



$P \rightarrow$ power of the circuit.

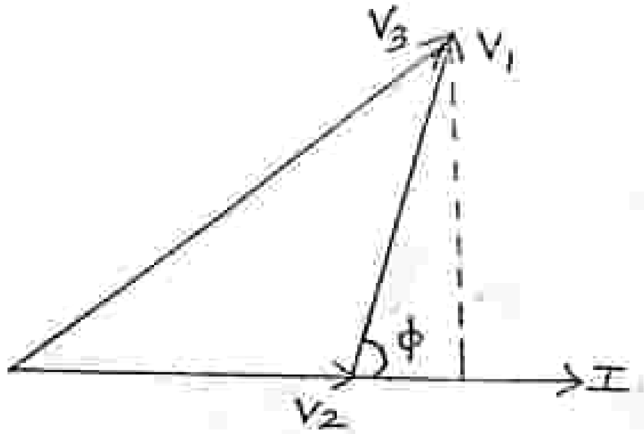
$\cos\phi \rightarrow$ power factor

V_1, V_2 & V_3 $\rightarrow$ voltage drops measured by 3 voltmeters.

$R \rightarrow$ pure resistance.

$$\therefore \vec{V_1} + \vec{V_2} = \vec{V_3}.$$

V_2 is in phase with I.



From the phasor dig.,

$$V_3^2 = V_1^2 + V_2^2 + 2V_1 V_2 \cos\phi.$$

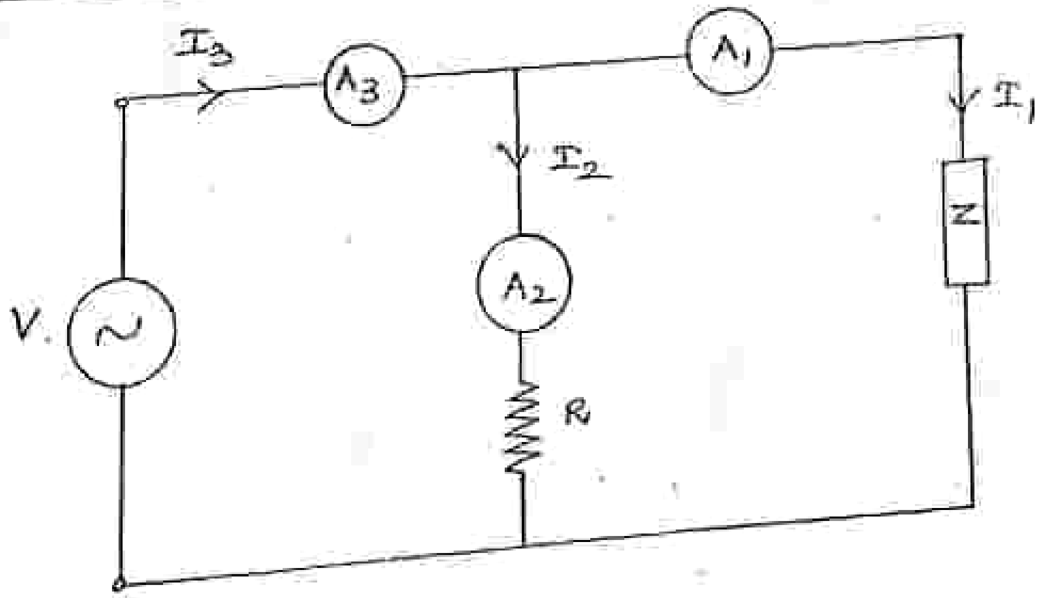
$$= V_1^2 + V_2^2 + 2V_1 (IR_1)\cos\phi.$$

$$= V_1^2 + V_2^2 + 2PR_1. \qquad P = V_1 I \cos\phi.$$

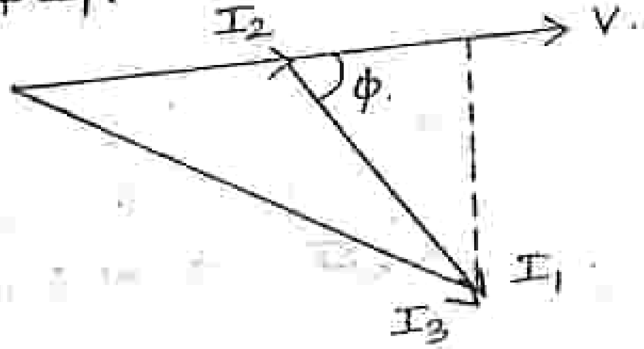
$$P = \frac{V_3^2 - V_1^2 - V_2^2}{2R_1}.$$

$$\cos\phi = \frac{V_3^2 - V_1^2 - V_2^2}{2V_1 V_2}.$$

2) 3-Ammeter Method :-



$$\vec{I_3} = \vec{I_2} + \vec{I_1}.$$



From the phasor dig.,

$$I_3^2 = I_1^2 + I_2^2 + 2 I_1 I_2 \cos\phi.$$

$$\cos\phi = \frac{I_3^2 - I_1^2 - I_2^2}{2 I_1 I_2}.$$

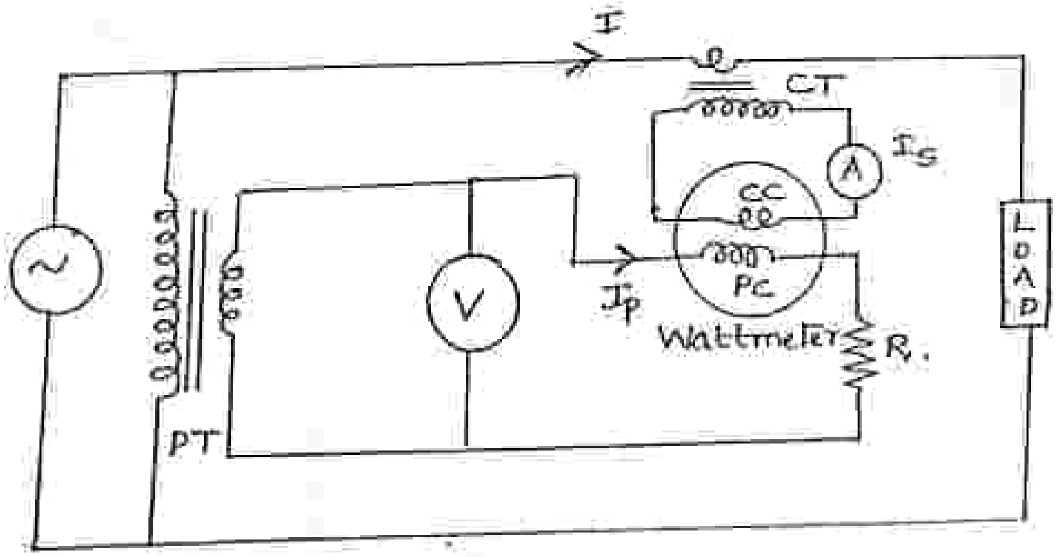
$$I_2 = \frac{V}{R_1}.$$

$$I_3^2 = I_1^2 + I_2^2 + 2 I_1 \left(\frac{V}{R}\right)\cos\phi.$$

$$I_3^2 = I_1^2 + I_2^2 + \frac{2P}{R_1}.$$

$$P = \frac{R_1}{2}\left(I_3^2 - I_1^2 - I_2^2\right).$$

3) Using Instrument Transformers :-



When high voltages and currents are to be measured, then instrument transformers are used.

Let $V \rightarrow$ load voltage

$I \rightarrow$ current

$\cos\phi \rightarrow$ load power factor.

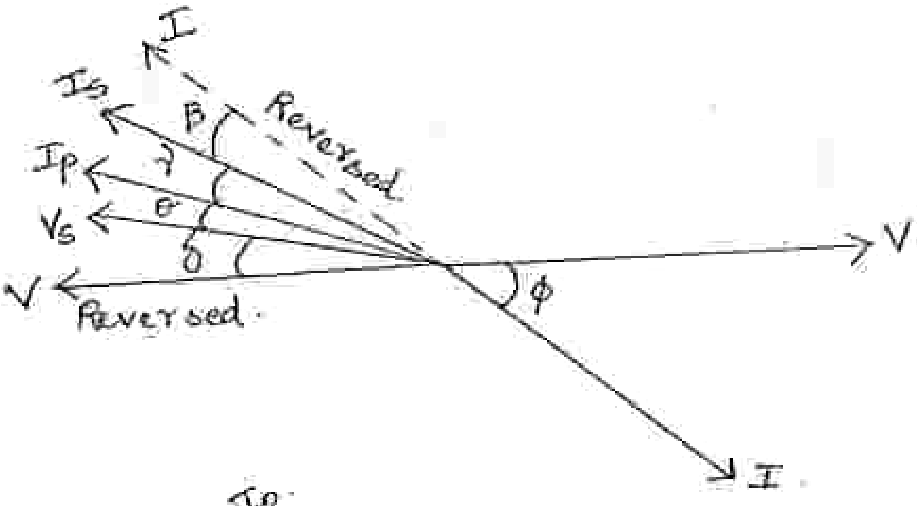
Current in the current coil of wattmeter = Current in secondary of CT = I_s.

Voltage across pressure coil of wattmeter = Voltage across secondary of PT = V_s.

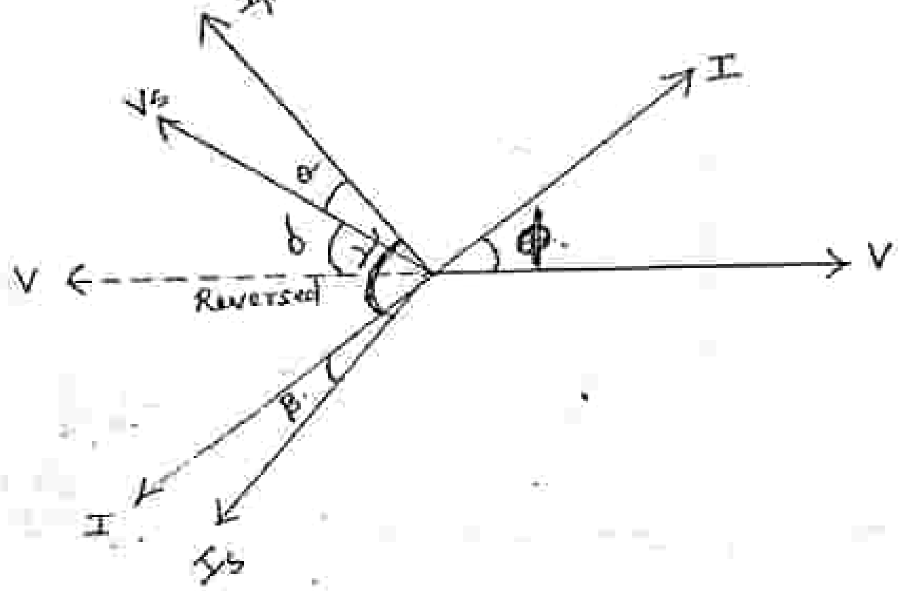
Current in pressure coil of wattmeter = I_p lagging behind V_s by a small angle θ due to inductance of pressure coil.

phase angle of PT = δ

phase angle of CT = β.



phasor dig. for Inductive load.



phasor dig. for capacitive load.

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Phase angle between the currents in current + potential coils of wattmeter

$\gamma = \phi - \theta - \beta \pm \delta$ for inductive loads.

$\gamma = \phi + \theta + \beta \pm \delta$ for capacitive loads.

Since phase angle of PT may be lagging or leading.

Correction factor

$$K = \frac{\cos\phi}{\cos\theta \cdot \cos(\phi - \theta - \beta \pm \delta)}$$ (for inductive loads)

$$K = \frac{\cos\phi}{\cos\theta \cdot \cos(\phi + \theta + \beta \pm \delta)}$$ (for capacitive loads)

True power = K × Actual ratio of CT × Actual ratio of PT × Wattmeter reading

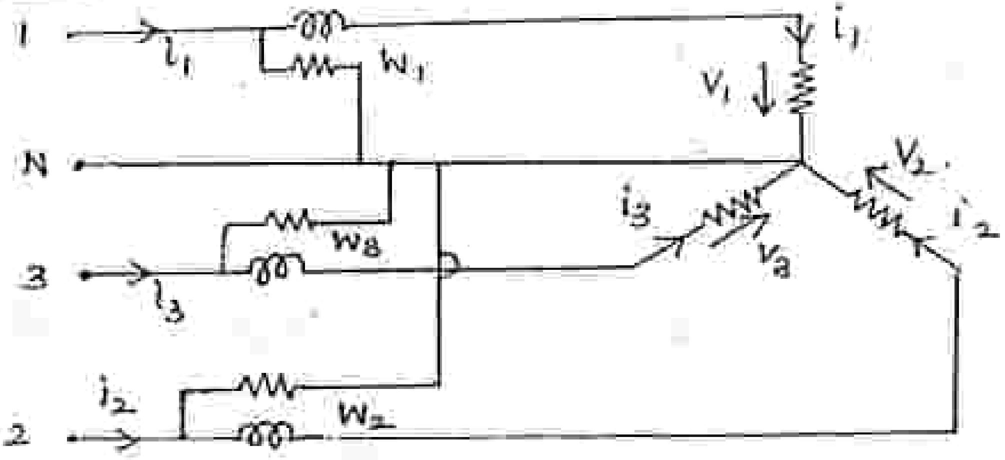
MEASUREMENT OF 3-φ POWER :-

1) Three Wattmeter Method.

2) One Wattmeter Method.

3) Two Wattmeter Method.

1) Three Wattmeter Method :-

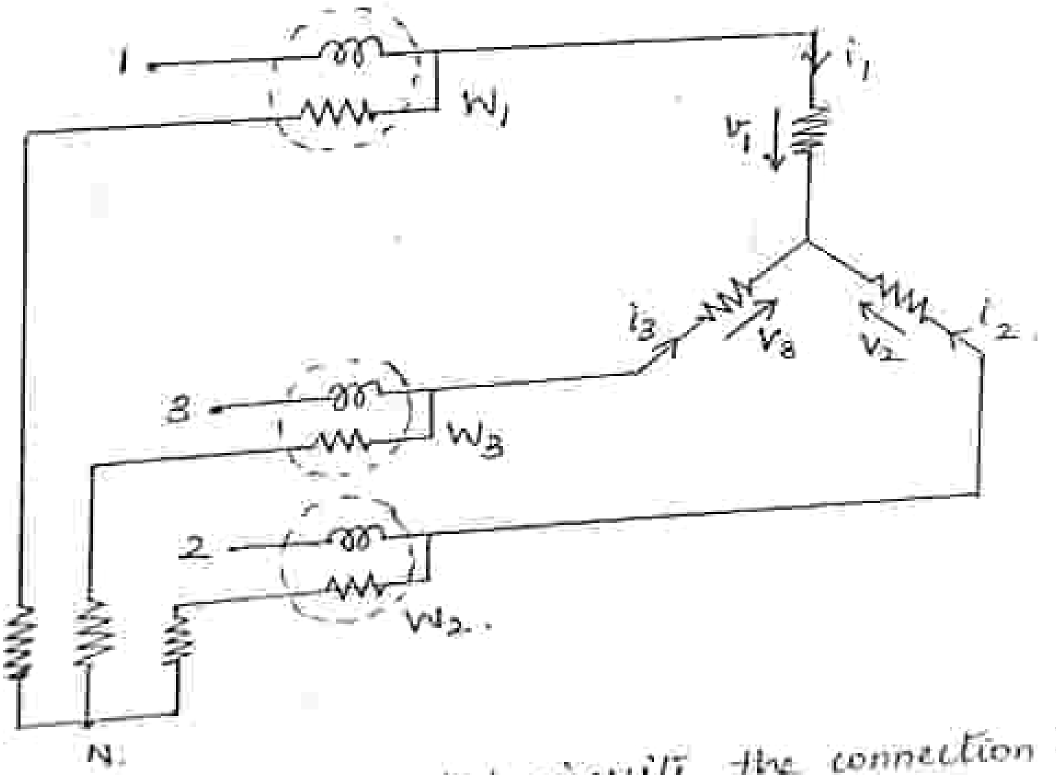


The neutral wire is common to the three phases. Each wattmeter reads power in its own phase.

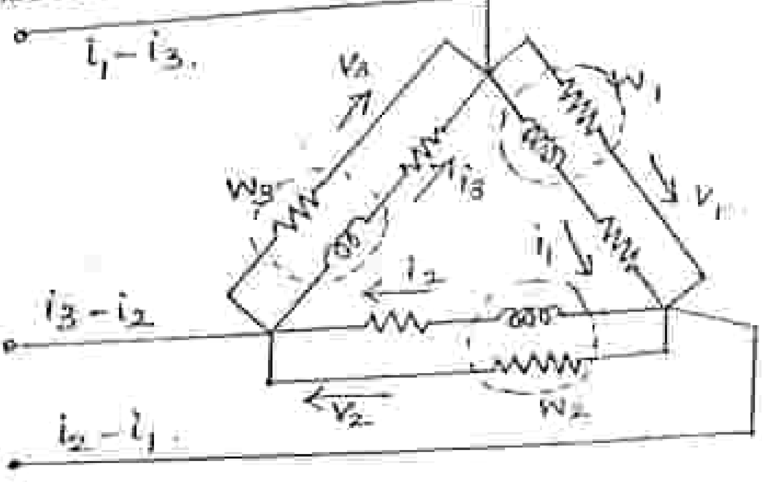
$\therefore$ Total power of load circuit $P = W_1 + W_2 + W_3$.

This is useful only in 3-ϕ, 4-wire load circuits.

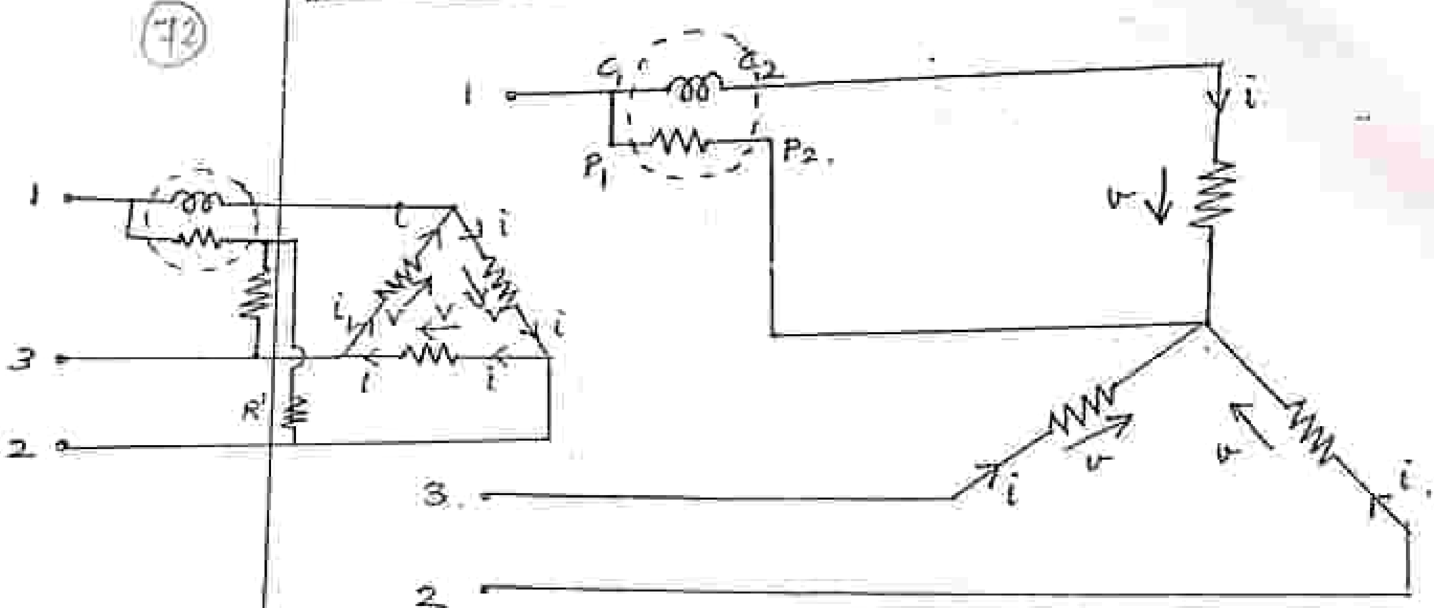
In case of 3-ϕ, 3-wire circuits, the connection is as shown. Here "artificial star" is formed by connecting three equal high resistances to the three line conductors.



In case of delta-connected circuits, the connection is as shown.



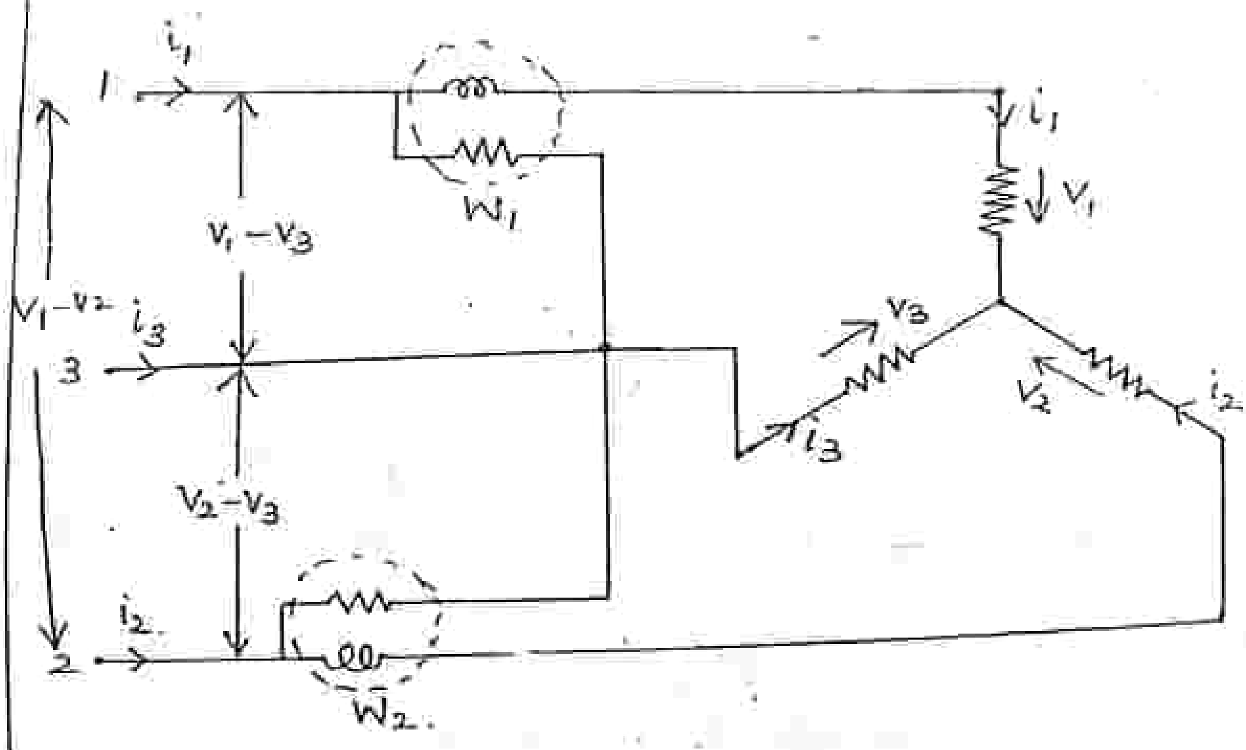
2) One - Wattmeter Method :-

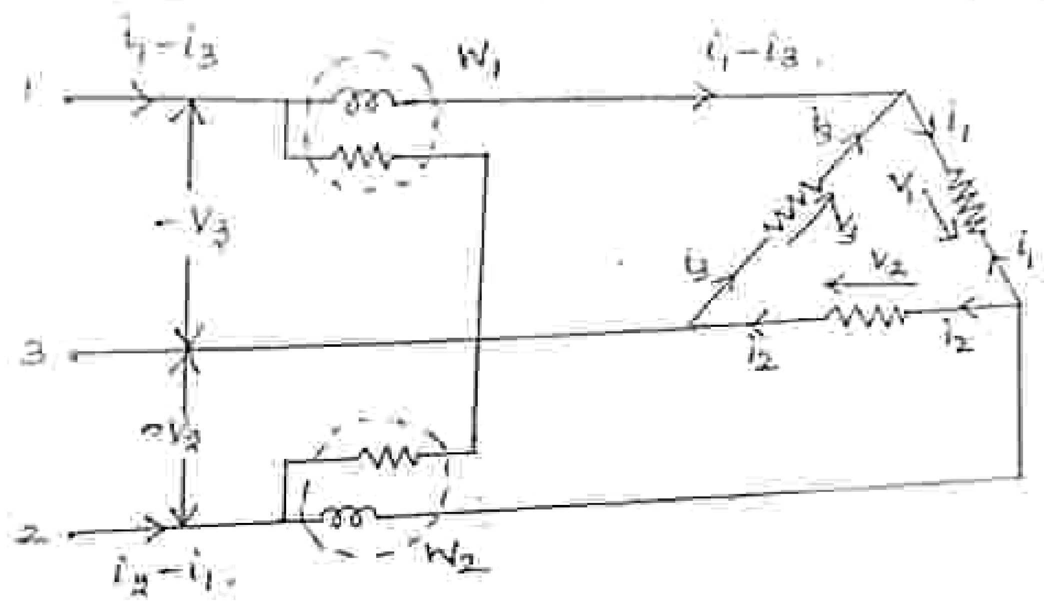


Here power is measured in any one phase. Since this is a 3-wire, 3-ϕ, balanced load circuit, the power in each phase is equal.

$\therefore$ Total power of the circuit = 3 x power measured in any one phase.

3) Two Wattmeter Method :-





Instantaneous power

$$p = v_1 i_1 + v_2 i_2 + v_3 i_3.$$

a) Star-connected system :-

All the three phases meet at a star point, so according to Kirchoff's law, the algebraic sum of three instantaneous currents is zero.

$$i_1 + i_2 + i_3 = 0.$$

$$i_3 = -(i_1 + i_2)$$

$$\therefore p = v_1 i_1 + v_2 i_2 - v_3 (i_1 + i_2)$$

$$p = i_1 (v_1 - v_3) + i_2 (v_2 - v_3)$$

$i_1 \rightarrow$ instantaneous current flowing through the current coil.

$v_1 - v_3 \rightarrow$ instantaneous potential difference across the pressure coil.

$$\therefore W_1 = (v_1 - v_3) i_1.$$

IIIly, $W_2 = (v_2 - v_3) i_2.$

Hence,

Total instantaneous power $= W_1 + W_2$.

74 **b) Delta - Connected System :-**

In delta-connected system, the three phas form a closed loop and according to kirchof 2nd law,

$$V_1 + V_2 + V_3 = 0.$$

$$V_1 = -(V_2 + V_3).$$

$$P = V_1 i_1 + V_2 i_2 + V_3 i_3.$$

$$= -(V_2 + V_3) i_1 + V_2 i_2 + V_3 i_3.$$

$$= -V_3 (i_1 - i_3) + V_2 (i_2 - i_1).$$

From fig. of delta connection,

$-V_3 \Rightarrow$ potential diff. across pressure coil of wattmeter 1.

$(i_1 - i_3) \Rightarrow$ instantaneous current flowing through current coil of W_1.

$$\therefore P = W_1 + W_2.$$

BLONDEL'S THEOREM :-

Two wattmeter methods of measurement of power in 3-ϕ, 3-wire load circuits and 3- wattme method of measurement of power in 3-ϕ, 4-wire load circuits are the most common applications o a general theorem known as Blondel's Theorem.

In an N-wire circuit, the total power supplie is given by the algebraic sum of the readings of N wattmeters, so arranged that a current coil of a wattmeter is in each wire and the corresponding potential coil is connected between that wire and a common point on the system.

If the common point is located on one of the wires, the potential difference across the potential coil circuit of the wattmeter whose current coil is in that wire is zero, and the wattmeter has a zero reading. Thus then only N-1 wattmeters are required.

eg:- 2 wattmeters for 3-wire circuit.
3 wattmeters for 4-wire circuit.

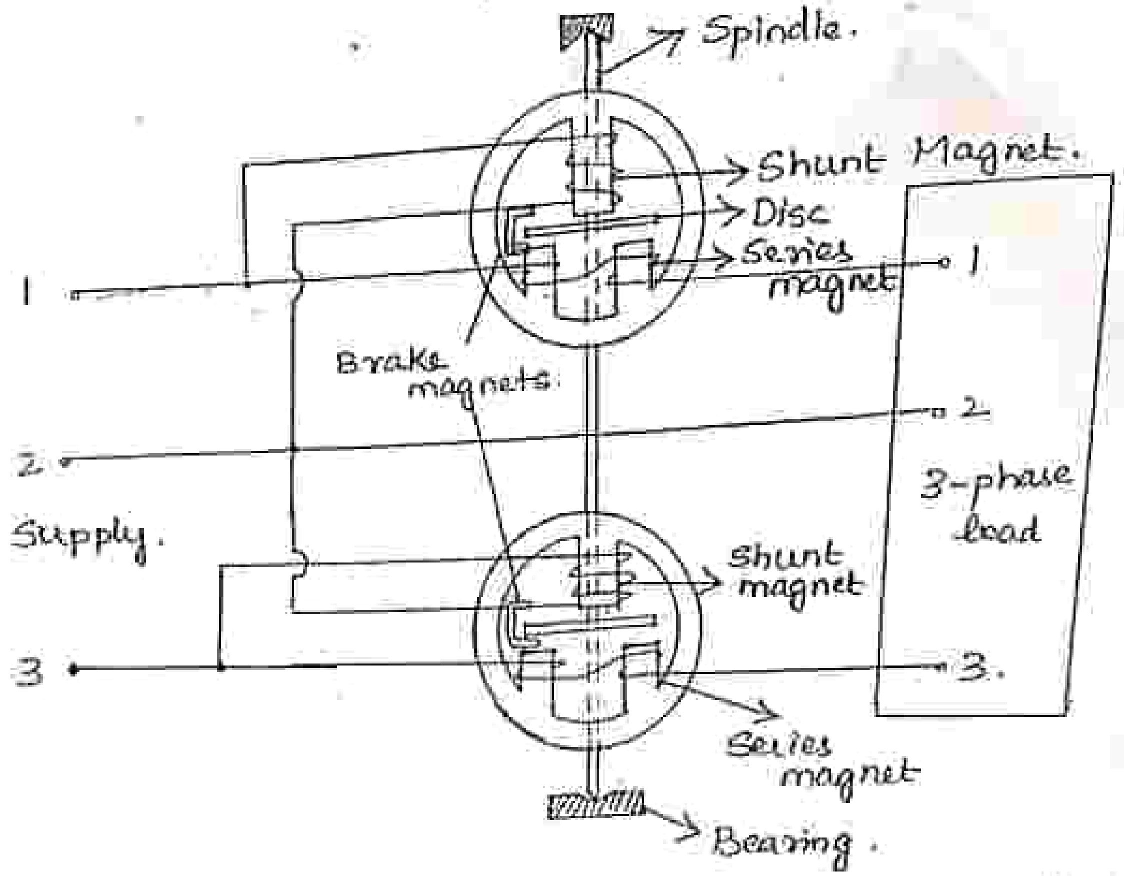
3-ϕ INDUCTION TYPE ENERGY METER:-

Energy in polyphase circuits can be measured by a group of single phase energy meters connected as required by Blondel's Theorem. The total energy is the sum of the readings of all energy meters. However, in commercial measurements, the above arrangement is not used but instead polyphase energy meters are used.

In polyphase wattmeters, the elements are mounted on the same spindle which drives the registering mechanism. Thus the registering mechanism registers the net effect of all the elements.

Two-Element Energy Meter:-

This is used for 3-ϕ, 3-wire systems. The meter is provided with 2 discs, one for each element. The driving torque of the two elements should be exactly equal for equal amounts of power passing through each.



In addition to normal compensating devices attached to each element, an adjustable magnetic shunt is provided on one or both the elements to balance the torque of the two.

The necessary arrangement is made with the coils energized from a single phase supply.

The pressure coils are connected in parallel and the current coils in series in such a manner that the torques produced by the two elements oppose each other.

The magnetic shunt is adjusted to a position where the two torques are exactly equal and opposite and therefore there is no rotation of disc.

ELECTRONIC ENERGY METER :-

They are accurate, precise and reliable type of measuring instruments when compared to electromechanical induction type meters. When connected to loads, they consume less power and start measuring instantaneously.

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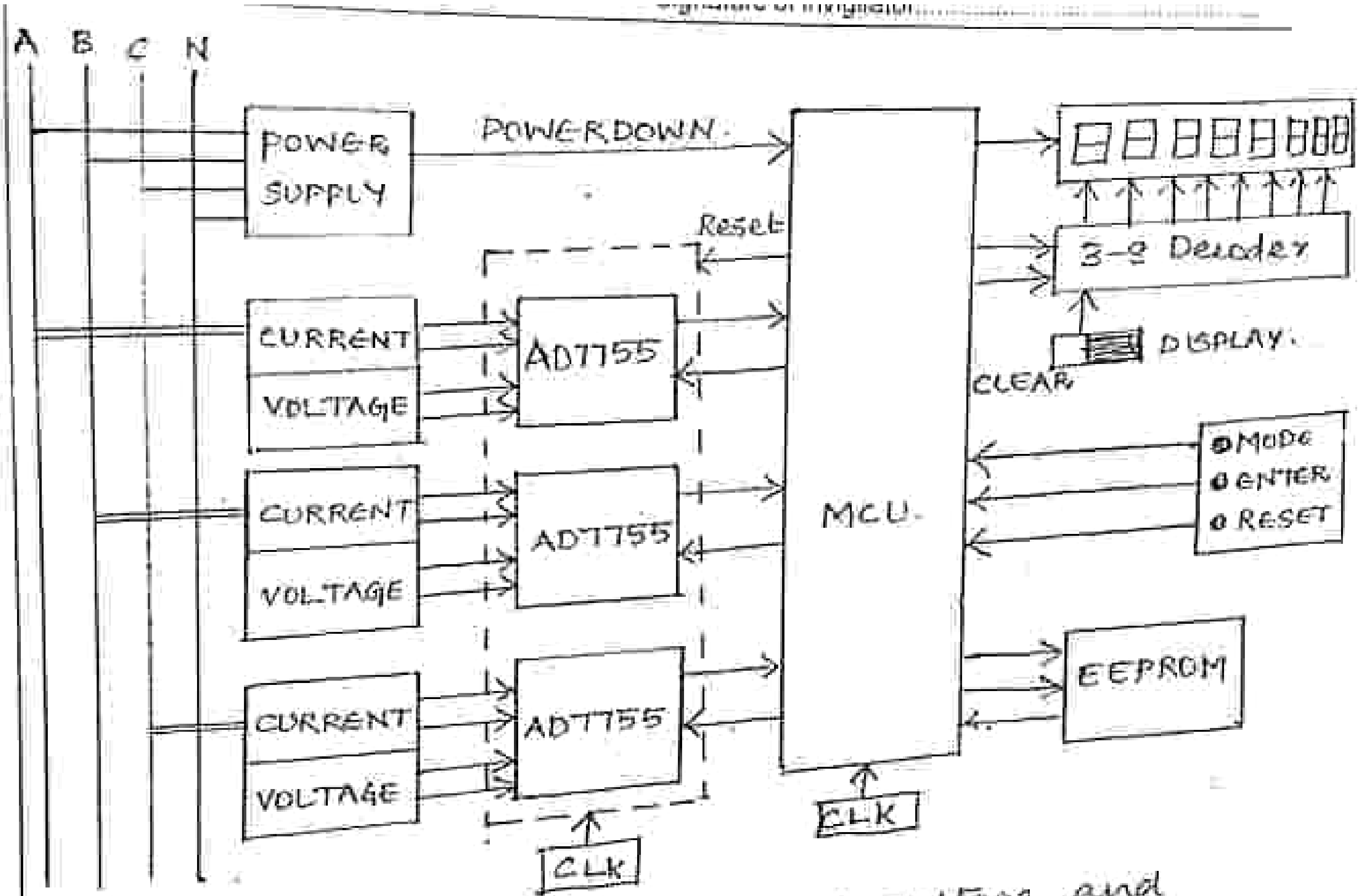


This meter is able to perform current, voltage and power measurements in three phase supply systems.

* It uses AD7755, a 1-φ energy measurement IC to acquire and process the input voltage and current parameters.

* The voltage and currents of the power line are scaled down to measurable level using transducers like voltage and current transformers. After that it is given to the AD7755 IC.

* These signals are sampled and converted into digital. Then the voltage signal & current signal are multiplied to get the instantaneous power.

* Later, these digital outputs are converted to frequency to drive an electromechanical counter.

* The frequency rate of the o/p pulse is proportional to the instantaneous power, 78 and in a given interval, it gives the energy transferred to the load for a particular no. of pulses.

* The microcontroller accepts the inputs from all the three energy measurement ICs for three phase energy measurement and serves as the brain of the system by performing all the necessary operations like storing and retrieving data from EEPROM, operating the meter using buttons to view energy consumption, calibrating phases and clearing readings. It also drives the display using decoder IC.

TOD METER :-

A Time of Day Energy meter or a Time of Usage Energy meter is an energy meter which measures the energy consumed and also the time of day it was consumed.

The time of day energy meter is used in many countries where the consumer is charged based on the time of day the power was consumed.

The time of Day energy meter gives its out in the form of slabs with the energy units and the time. The utility then applies the cost per un depending on the time and the customer gets the final bill.

The Time of day helps encourage customers to use power during the off-peak hours. It is a used in power wheeling in which private power producers use the transmission lines of a utility to transfer power.

MODULE - 3

INTRODUCTION TO HIGH VOLTAGE AND HIGH CURRENT MEASUREMENTS

MEASUREMENT OF HIGH DC VOLTAGES

The different methods used are:

1. Series Resistance micro ammeter
2. Resistance potential divider
3. Generating Voltmeters
4. Sphere Gaps

MEASUREMENT OF HIGH AC VOLTAGES

1. Series Impedance Voltmeter
2. Potential Transformers
3. Electrostatic Voltmeters
4. Potential Dividers
5. Sphere gaps

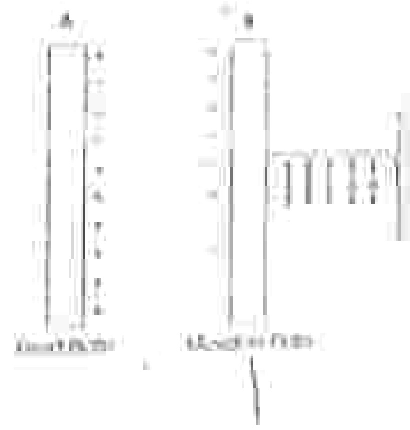
ELECTROSTATIC VOLTMETERS:

- In electrostatic instruments, the deflecting torque is produced by the action of electric field on a charged conductor.
- Such instrument are essentially voltmeters, but they may be used with the help of external components, to measure current and power.
- Their greater use is in laboratory for measurement of high voltages

There are two way in which forces acts:

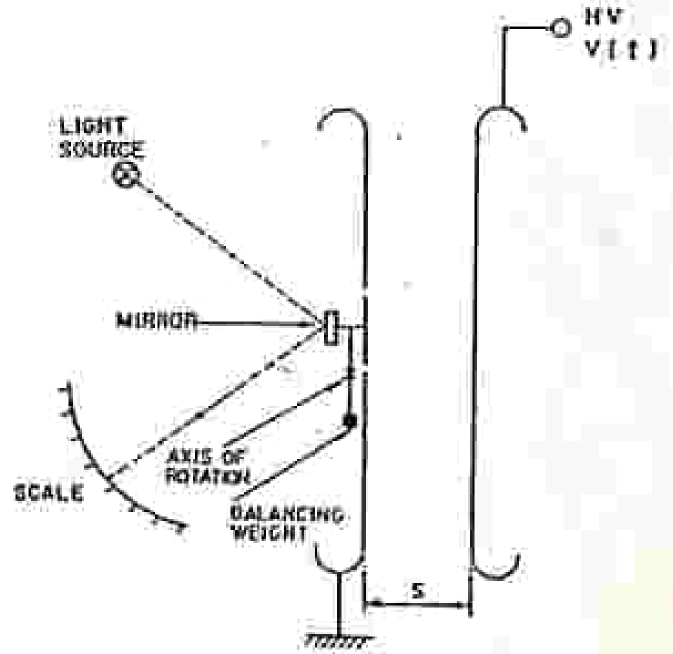
1. Attraction disc type electrostatic instrument
2. Quadrant electrometer.

Attraction disc type electrostatic instrument.



(3)

- One of the direct methods of measuring high voltages is by means of electro-static voltmeters.
- For voltages above 10 kV, generally the attracted disc type of electrostatic voltmeter is used.
- Electrostatic voltmeters of the attracted disc type may be connected across the high voltage circuit directly to measure up to about 200 kV, without the use of any potential divider or other reduction method.
- The right electrode forms the high voltage plate.
- The centre portion of the left disc is cut away and encloses a small disc which is movable and is geared to the pointer of the instrument.
- The range of the instrument can be altered by setting the right disc at pre-marked distances.
- The force of attraction F(t) created by the applied voltage causes the movable part-to which a mirror is attached-to assume a position at which a balance of forces takes place.
- An incident light beam will therefore be reflected toward a scale calibrated to read the applied voltage magnitude.



DERIVATION:

FINAL CAPACITANCE = C + dC

FINAL VOLTAGE = V + dV

Initial energy = ½ CV^2

Final Energy = ½ (C+ dC) $(V+dV)^2$

Change in energy = Final energy – Initial Energy =

= ½ (C+ dC) $(V+dV)^2$ - ½ CV^2

Input Energy = V I dt

= V. dq/dt . dt (I = dq/dt)

= V. d(CV)/dt . dt

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$$= V.(C\,dV + V\,dC)$$

$$= VC\,dV + V^2\,dC$$

Work done = Force x Displacement

$$= F \times dS$$

Input energy = Change in energy + Work done

$$VC\,dV + V^2\,dC = ½(C + dC)(V+dV)^2 - ½CV^2 + F \times dS$$

Ignoring Higher order terms

$$F = ½ V^2\, dC/dS \text{ Newton}$$

$$F = \frac{1}{2} V^2 \frac{dC}{dS} \text{ N.}$$

Force of attraction is proportional to the square of the potential difference applied, so that the meter reads the square value (or can be marked to read the rms value).

ADVANTAGES:

1. Low loading effect
2. Active power losses are negligibly small
3. Voltage source loading is limited to the reactive power needed to charge the system capacitance.(i.e., For 1V Voltmeter- Capacitance is few Pico farad)
4. Voltages up to 600kV can be measured.

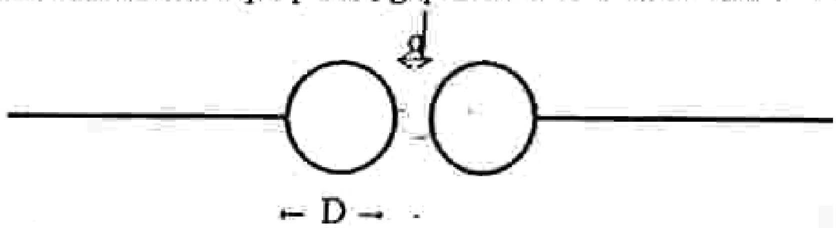
DISADVANTAGES:

1. For constant distance 's', $F \alpha V^2$, the sensitivity is small. This can be overcome by varying the gap distance s in appropriate steps.
2. These instruments are expensive, large in size and are not robust in construction.
3. There scale are not uniform.

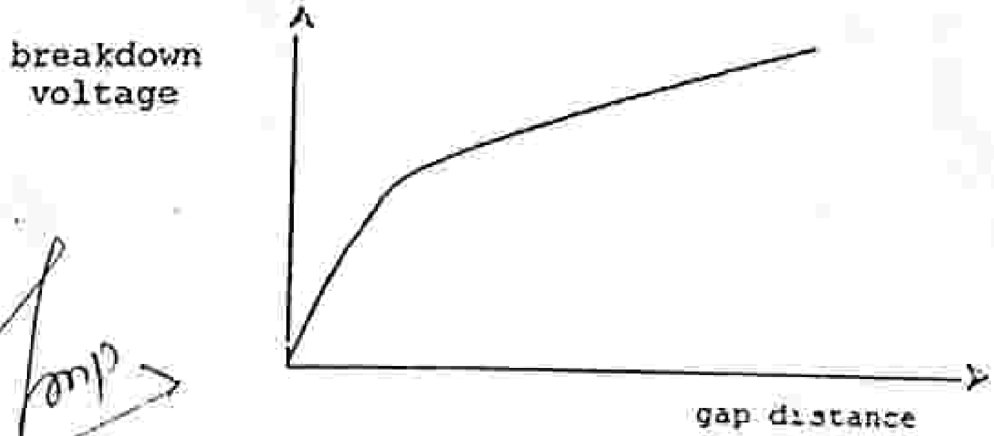
SPHERE GAPS:

- Two adjacent metal spheres of equal diameters, whose separation distance is limited, form a sphere gap for the measurement of the peak value of either AC, DC or both types of impulse voltages.
- A spark gap may be used for the determination of the peak value of a voltage wave, and for the checking and calibrating of voltmeters and other voltage measuring devices.
- Basic mechanisms of HV measurement by sphere gaps
    - Breakdown voltage of air gap in uniform field is determined by gap distance
    - A quasi-uniform field between the two spheres
- 2 Configurations possible:
    1. vertically with lower sphere grounded
    2. horizontally with both spheres connected to the source voltage or one sphere grounded
- The breakdown strength of a gas depends on the ionization of the gas molecules, and on the density of the gas
- The breakdown voltage varies with the gap spacing; and for a uniform field gap, a high consistency could be obtained, so that the sphere gap is very useful as a measuring device.

- In the measuring device, two metal spheres are used, separated by a gas-gap.
- The potential difference between the spheres is raised until a spark passes between them.
- The breakdown strength of a gas depends on the size of the spheres, their distance apart and a number of other factors.
- The density of the gas (generally air) affects the spark-over voltage for a given gap setting. Thus the correction for any air density change must be made. The air density correction factor δ must be used.
- The spark over voltage for a given gap setting under the standard conditions (760 torr pressure and at 20oC) must be multiplied by the correction factor to obtain the actual spark-over voltage.
- When the gap distance is increased, the uniform field between the spheres becomes distorted, and accuracy falls. The limits of accuracy are dependent on the ratio of the spacing d to the sphere diameter D, as follows
- $d < 0.5\,D$, accuracy $= \pm 3\,\%$ $0.75\,D > d > 0.5\,D$, accuracy $= \pm 5\,\%$
- For accurate measurement purposes, gap distances in excess of 0.75D are not used

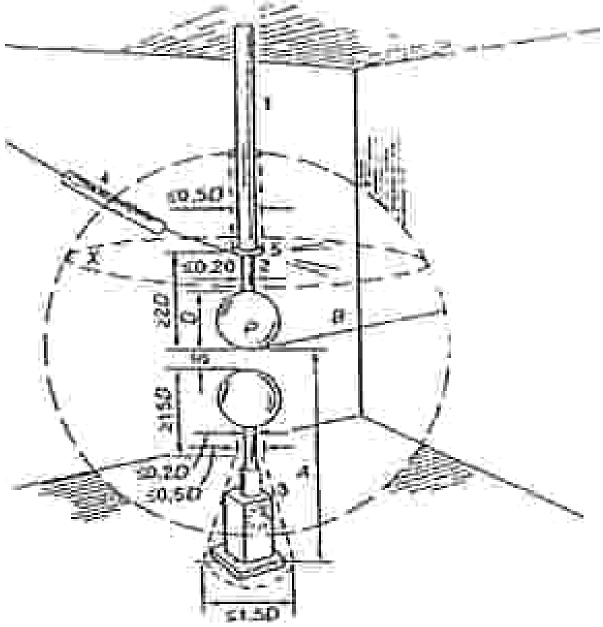


where d = gap spacing, D = sphere diameter



Breakdown voltage characteristic of sphere gaps

Vertical sphere gap



1. Insulating support
2. Sphere shank
3. Operating gear, showing maximum dimensions
4. High-voltage connection with series resistor
5. Stress distributor, showing maximum dimensions.

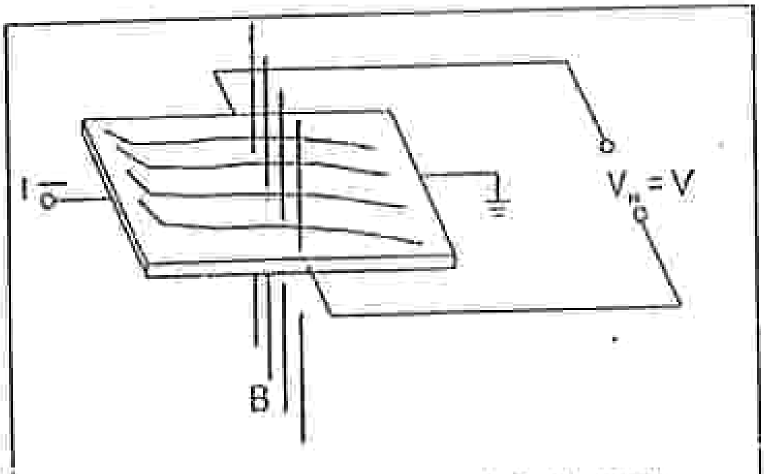
P. Sparking point of HV sphere
A. Height of P above ground plane.
B. Radius of space free from external structures
X. Item 4 not to pass through this plane within a distance B from P.

Note: The figure is drawn to scale for a 100-cm sphere gap at radius spacing.

- To avoid excessive pitting of the spheres, protective series resistances may be placed between test object and sphere gap.
- For AC and DC voltages, the value of the protective resistor may range from 0.1 to 1 MΩ.
- For impulse voltages, it should not exceed 500 ohms and its inductance should be smaller than 30 Mh.

HALL EFFECT SENSORS:

- The Hall effect was discovered by Dr. Edwin Hall in 1879.
- If a current flows in a conductor (or semiconductor) and there is a magnetic field present that is perpendicular to the current flow, then the combination of current and magnetic field will generate a voltage perpendicular to both. This phenomenon is called the **Hall effect.**
- The generated voltage is known as Hall voltage and is approximately linear to the magnetic flux density.



Hall effect principle, magnetic field present

- A single device that works as a magneto-electric transducer and uses the Hall effect to measure or sense a magnetic field is called a Hall element.
- For digital applications the Hall element is combined with signal-conditioning circuitry in a single package, referred to as a Hall-effect (switch) integrated circuit (IC), that converts the internal Hall element analog output into a digital output.
- As the Hall element reacts to the magnetic flux perpendicular to its surface, therefore, the placement of the Hall element with respect to the magnetic field of the magnet (its position and strength) is important for correct IC operation.
- The Hall effect is an ideal sensing technology.
- The Hall element is constructed from a thin sheet of conductive material with output connections perpendicular to the direction of current flow.
- When subjected to a magnetic field, it responds with an output voltage proportional to the magnetic field strength. The voltage output is very small (μV) and requires additional electronics to achieve useful voltage levels.
- When the Hall element is combined with the associated electronics, it forms a Hall effect sensor. The heart of every Hall effect device is the integrated circuit chip that contains the Hall element and the signal conditioning electronics.

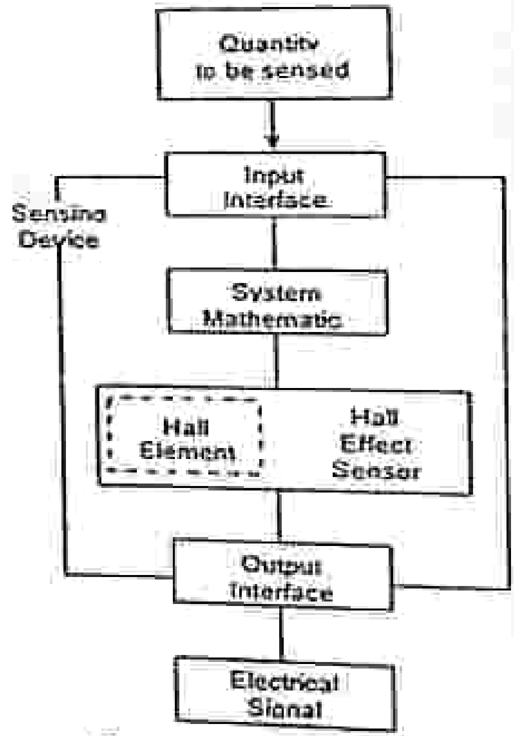
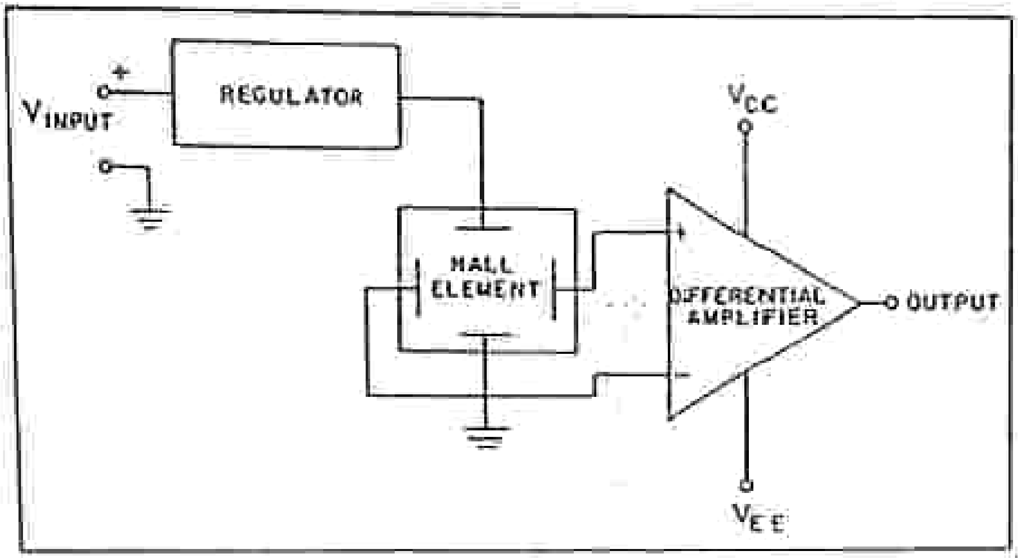


Figure General sensor based on the Hall effect

- In this generalized sensing device, the Hall sensor senses the field produced by the magnetic system.
- The magnetic system responds to the physical quantity to be sensed (temperature, pressure, position, etc.) through the input interface.
- The output interface converts the electrical signal from the Hall sensor to a signal that meets the requirements of the application
- The Hall element is the basic magnetic field sensor.

- It requires signal conditioning to make the output usable for most applications.
- The signal conditioning electronics needed are an amplifier stage and temperature compensation.
- Voltage regulation is needed when operating from an unregulated supply.



- The amplifier shown in Figure must be a differential amplifier so as to amplify only the potential difference – the Hall voltage.
- The Hall voltage is a low-level signal of the order of 30 micro volts in the presence of a one gauss magnetic field. This low-level output requires an amplifier with low noise, high input impedance and moderate gain - standard bipolar transistor technology
- General features of Hall effect based sensing devices are:
  - True solid state
  - Long life
  - High speed operation - over 100 kHz possible
  - Operates with stationary input (zero speed)
  - No moving parts
  - Logic compatible input and output
  - Broad temperature range (-40 to +150°C)
  - Highly repeatable operation

PHASOR MEASUREMENT UNITS:

ALSO CALLED SYNCHROPHASORS

- A Synchrophasor is a phasor that is time stamped to an extremely precise and accurate time reference.
- Basically a solid-state relay or digital fault recorder with GPS clock.
- Synchronized phasors (synchrophasors) provide a real-time measurement of electrical quantities across the power system.

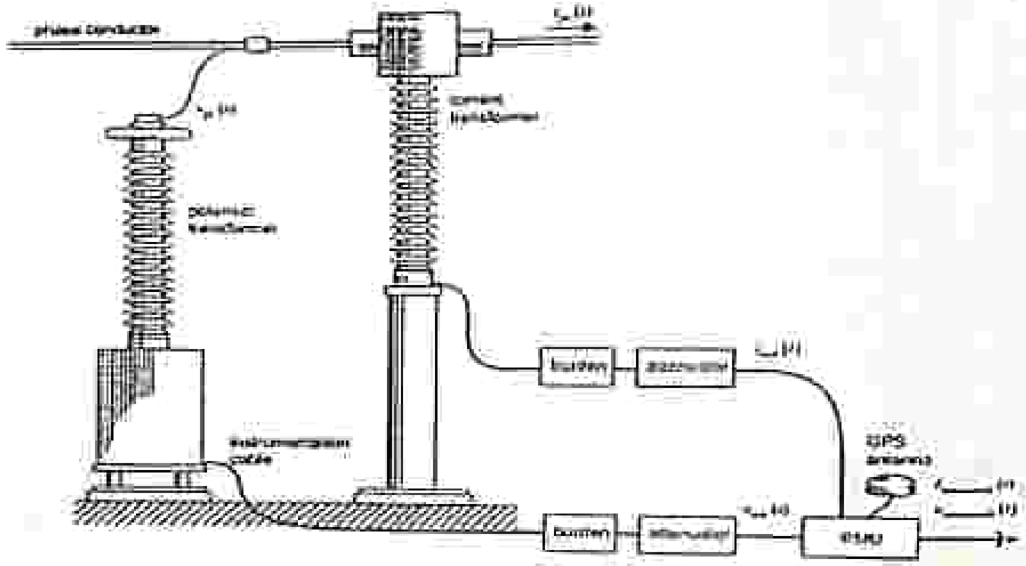
➢ The resultant time tagged phasors can be transmitted to a local or remote receiver at rates up to 60 samples per second.

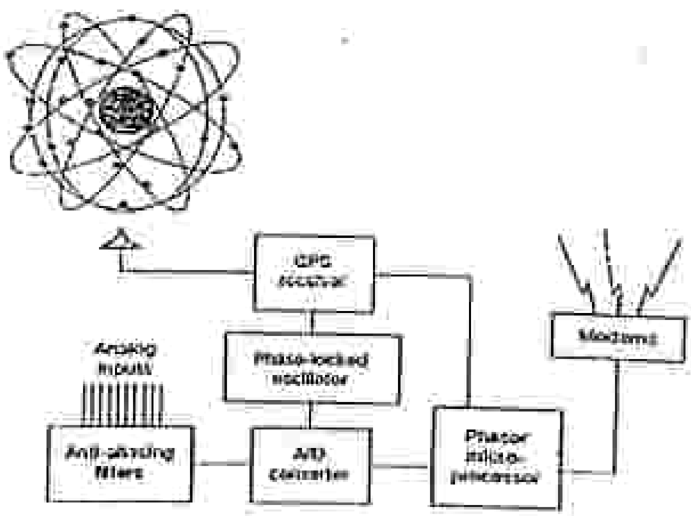
➢ Continuously measures voltages and current phasors and other key parameters and transmits time stamped messages.

➢ Phasor Measurement Units (PMUs) Provide Synchronized, Wide-Area Power Measurements

➢ PMUs provide the Magnitude and Angle of all power measurements at all grid locations simultaneously

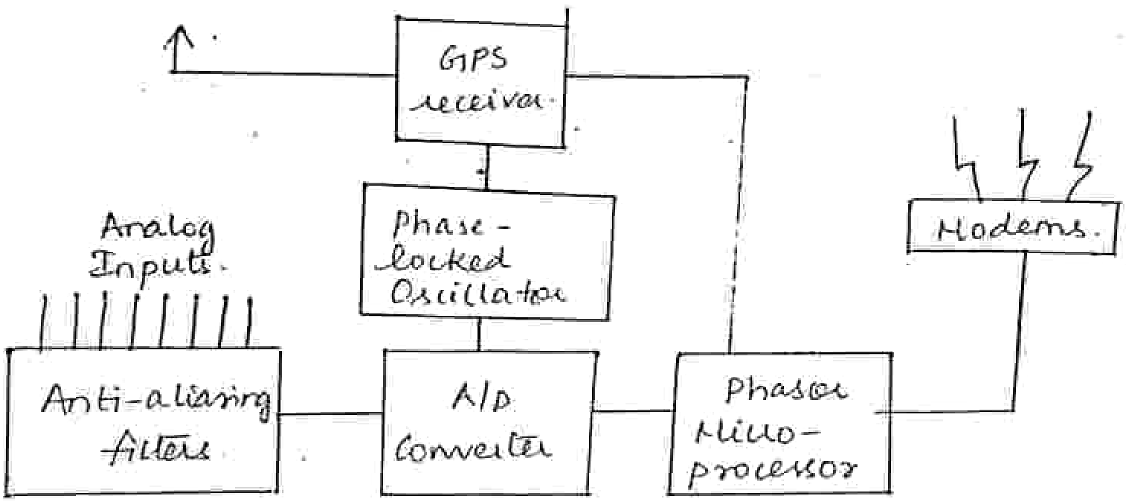
➢ Measurements are available as frequently as 30 times each second





- PMUs measure (synchronously)
  - ☐ Positive sequence voltages and currents
  - ☐ Phase voltages and currents
  - ☐ Local frequency
  - ☐ Local rate of change of frequency
  - ☐ Circuit breaker and switch status.

BLOCK DIAGRAM :-



PHASOR MEASUREMENT UNIT

Series Transformer / Step up transformer

(89)

Current Transformers

Imp

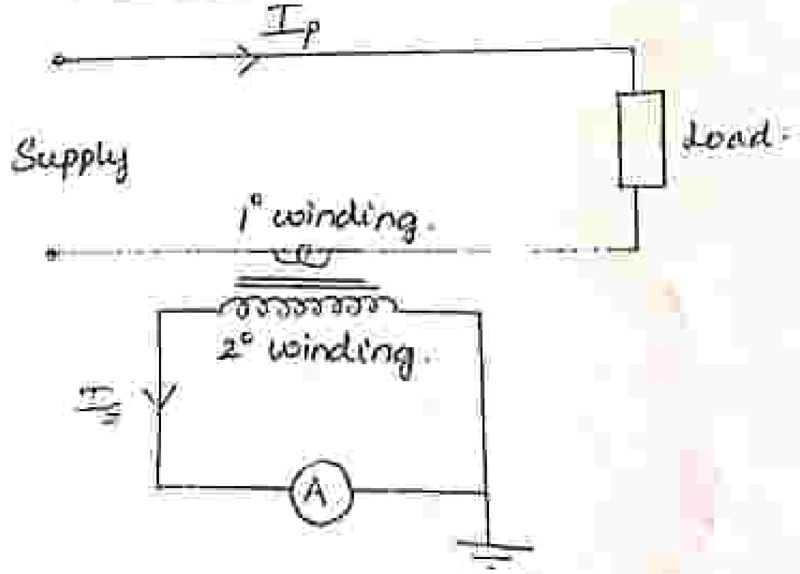
Transformer used in connection with measuring instruments for measurement purposes are called instrument transformer.

The transformer used in measurement of current is called a "Current Transformer" or C.T.

The transformer used in measurement of voltage is called "Voltage Transformer" or "Potential Transformer" or P.T.

C.T is also known as Series Transformer
P.T is also known as Parallel Transformer

PRINCIPLE OF WORKING :-



The power in a transformer remains the same in both primary and secondary sides of the transformer. P = VI. So if the windings in secondary is more, the voltage is stepped up. Since the power remains constant, the current is stepped down. Hence the C.T is a step up transformer.

The primary winding is connected such that the current being measured passes through it and the secondary winding is connected to an ammeter. The C.T steps down the current to the level of ammeter.

The current transformer is used with its primary winding connected in series with the line carrying the current to be measured and hence the primary current I_p is dependent on the load connected to the system.

I_p is not dependent on the load connected to the secondary winding of the current transformer.

The primary winding has very few turns and hence there is no voltage drop across it.

The secondary winding has large number of turns. The no. of turns is determined by the turns ratio.

The ammeter is connected directly across the secondary winding terminals.

Thus a C.T operates its secondary winding nearly under short circuit conditions.

One of the terminals of the secondary winding is earthed to protect the equipment and persons working, if any insulation breakdown occurs in the C.T.

Phasor diagram

* flux ϕ is taken as the reference phasor
* The induced emf E_p and E_s lags behind the flux ϕ by 90°.
* The excitation current I_0 drawn by the primary is made up of two components, I_m & I_e

$I_m \rightarrow$ Magnetising component

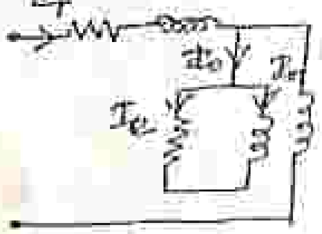
$I_e \rightarrow$ energy or active component.

$$I_0 = \sqrt{I_m^2 + I_e^2}$$

* $\vec{V_s} + \vec{I_s}\vec{R_s} + \vec{I_s}\vec{X_s} = \vec{E_s}$

Angle between $\vec{V_s}$ & $\vec{E_s}$ is δ and is usually negligible because the reactance of secondary winding is usually negligible.

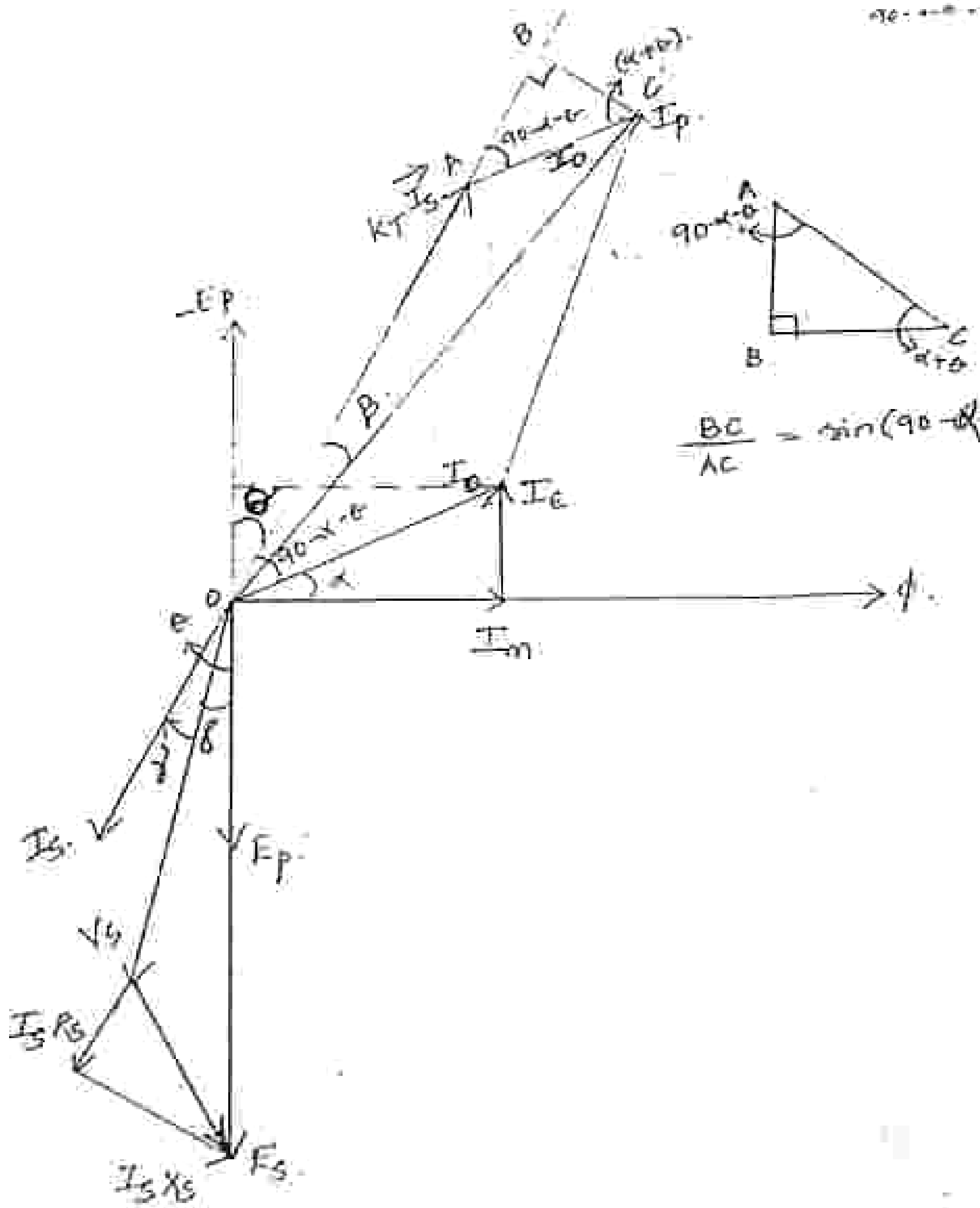
$\theta = \delta + \gamma$



* Now $\frac{I_p}{I_s} = K_T$.

$\vec{I_p} = K_T \vec{I_s}$.

* Also, I_p leads I_0.



$$\frac{BC}{AC} = \sin(90-\alpha-\theta)$$

Consider a small section of the phasor dig.

$AC = I_0$

$OA = K_T I_s$

$OC = I_p$

$$BC = I_0 \sin(90-\alpha-\theta)$$
$$= I_0 \sin[90-(\alpha+\theta)]$$
$$= I_0 \cos(\alpha+\theta)$$
$$AB = I_0 \cos(90-\alpha-\theta)$$
$$= I_0 \sin(\alpha+\theta)$$

(13)

$$OC^2 = OB^2 + BC^2$$

$$= (OA + AB)^2 + BC^2$$

$$= \left[K_T I_S + I_0 \sin(\alpha+\theta)\right]^2 + \left[I_0 \cos(\alpha+\theta)\right]^2$$

$$= \left[K_T^2 I_S^2 + I_0^2 \sin^2(\alpha+\theta) + 2 K_T I_S I_0 \sin(\alpha+\theta) + I_0^2 \cos^2(\alpha+\theta)\right]$$

$$I_p^2 = K_T^2 I_S^2 + I_0^2 + 2 K_T I_S I_0 \sin(\alpha+\theta).$$

$$I_p = \sqrt{K_T^2 I_S^2 + I_0^2 + 2 K_T I_S I_0 \sin(\alpha+\theta)}.$$

The actual current ratio,

$$K_C = \frac{\text{Primary winding current}}{\text{Secondary winding current}}$$

$$K_C = \frac{\sqrt{K_T^2 I_S^2 + I_0^2 + 2 K_T I_S I_0 \sin(\alpha+\theta)}}{I_S}.$$

For easy calculations,

$$I_0^2 \simeq I_0 \sin(\alpha+\theta)$$

$$K_C = \frac{\sqrt{\left[K_T I_S + I_0 \sin(\alpha+\theta)\right]^2}}{I_S}$$

$$\boxed{K_C = K_T + \frac{I_0}{I_S} \sin(\alpha+\theta)}$$

$\frac{I_p}{I_s} = \frac{N_s}{N_p} = K_T$ (ideal). But actually it is not so. The current ratio is not equal to turns ratio because of magnetising and core loss component of excitation current. This is called ratio error.

$$\% \text{ Ratio Error} = \frac{\text{Nominal ratio} - \text{Actual ratio}}{\text{Actual ratio}} \times 100$$

$$= \frac{K_n - K_c}{K_c} \times 100$$

$$K_c = K_T + \frac{I_0}{I_S} \sin(\alpha + \theta)$$

$$= K_T + \frac{I_0}{I_S} \left[\sin\alpha \cos\theta + \cos\alpha \sin\theta\right]$$

$I_0 \cos\alpha = I_m$, $I_0 \sin\alpha = I_e$

$$K_c = K_T + \frac{I_e \cos\theta + I_m \sin\theta}{I_S}$$

PHASE ANGLE ERROR :-

The angle by which the secondary current phasor when reversed differs in phase from the primary current is known as phase angle error of the transformer.

This error is due to the no load current or excitation current, due to the magnetising and iron loss components of exciting current.

From the phasor dig.,

$\beta \rightarrow$ phase angle error.

95

$$\tan\beta = \frac{BC}{OB} = \frac{BC}{OA+AB}$$

$$= \frac{I_0 \cos(\alpha+\theta)}{K_T I_s + I_0 \sin(\alpha+\theta)}$$

$I_0 << K_T I_s$

$$\tan\beta = \frac{I_0 \cos(\alpha+\theta)}{K_T I_s}$$

$$= \frac{I_0 \cos\alpha \cos\theta - I_0 \sin\alpha \sin\theta}{K_T I_s}$$

$$= \frac{I_m \cos\theta - I_e \sin\theta}{K_T I_s}$$

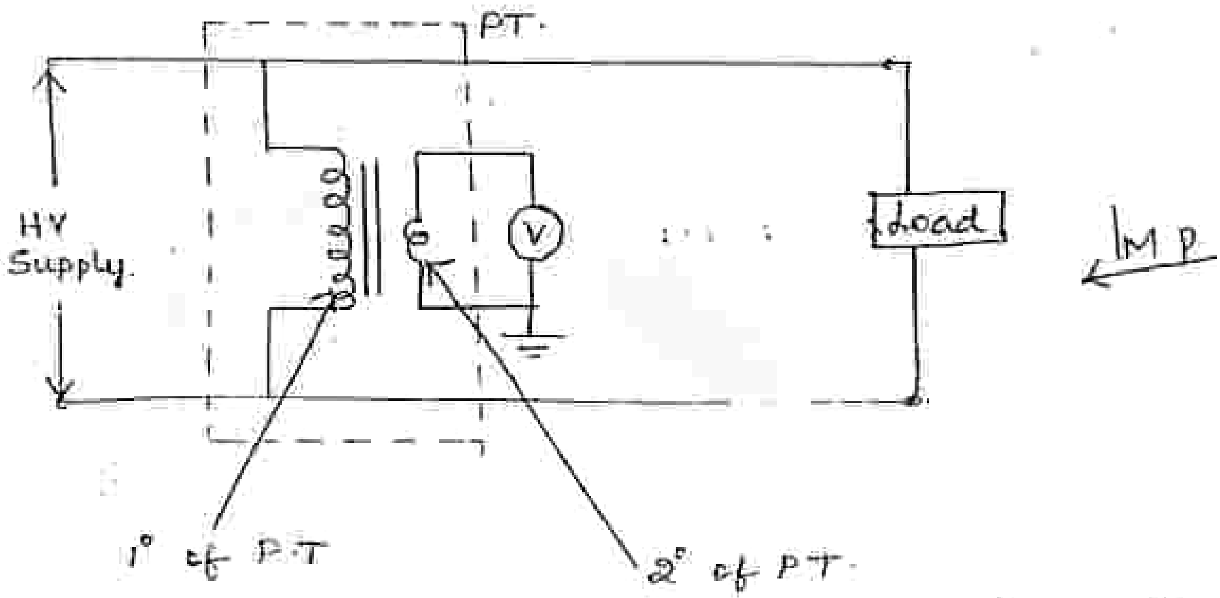
β is very small. Hence $\tan\beta = \beta$.

$$\beta = \frac{I_m \cos\theta - I_e \sin\theta}{K_T I_s}$$

$\tan(0.1) = 0.1$
$\tan(0.2) = 0.2$

$$\beta = \left(\frac{I_m \cos\theta - I_e \sin\theta}{K_T I_s}\right)\left(\frac{180}{\pi}\right) \text{ degree}$$

POTENTIAL TRANSFORMERS:-



* The high alternating voltage is reduced in a fixed proportion for measurement purpose with the help of P.T.

* The primary winding is connected across a high voltage line while the secondary winding is connected to the low range voltmeter coil.

* One end of the 2° is always grounded for safety purpose.

* The transformer ratio can be specified as,

$$\frac{V_2}{V_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2} = K_T.$$

* So if the voltage ratio of a P.T is known and the voltmeter reading is known, then the high voltage to be measured can be determined

RATIO ERROR

$$R_r = \frac{K_T V_S - V_P}{V_P} \times 100.$$

where,

K_T = Nominal ratio

Imp →

$$K_T = \frac{\text{Rated primary voltage}}{\text{Rated secondary voltage}}$$

PHASE ANGLE ERROR :-

$$\beta = \frac{\frac{I_S}{K_T}\left(X_p' \cos\phi - R_p' \sin\phi\right) + I_e X_p - I_m R_p}{K_T V_S}.$$

imp →

At no load,

$I_s = 0.$

$$\therefore \beta = \frac{I_e X_p - I_m R_p}{K_T V_S}.$$

$\phi \rightarrow$ angle between V_S & I_S.

CLAMP ON METER :-

* The instrument consists of a split-core current transformer. A rectifier moving coil instrument is permanently connected to the secondary of the current transformer.

* The split core can be opened out at a hinged section by merely pressing the spring loaded trigger and then clipped around a current carrying conductor which acts as a single turn primary

* The measurements are carried out simply by opening the magnetic core by pressing the trigger and then clipping over the current carrying conductor

* The ammeter connected to the secondary of the split-core current transformer gives the value of current flowing through the conductor.

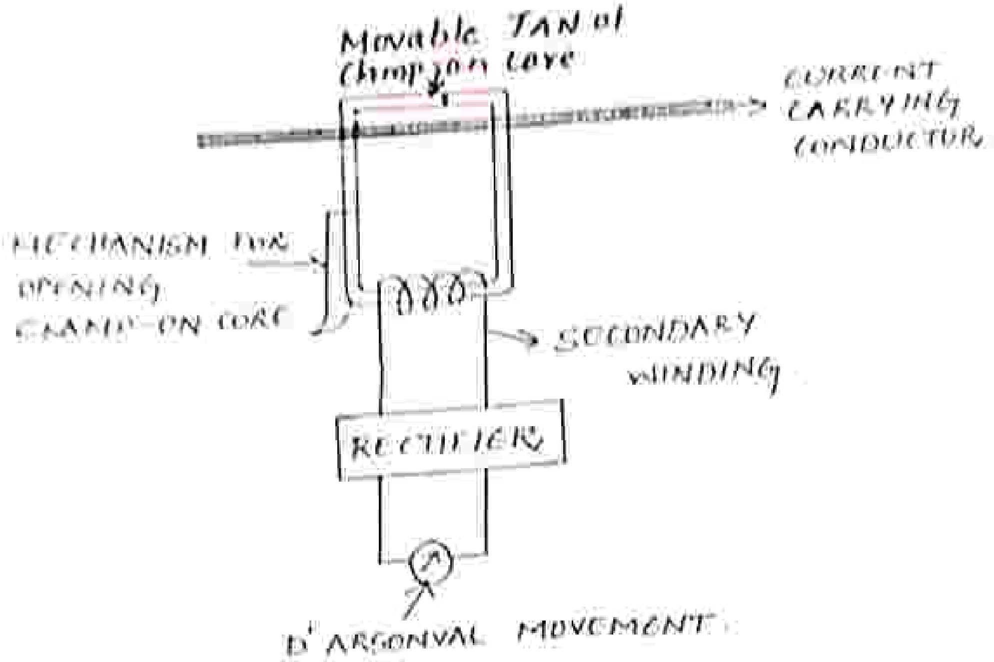
* Although the clamp on ammeter is very convenient for making rapid ac current measurements its use is limited to measuring relatively high current levels.

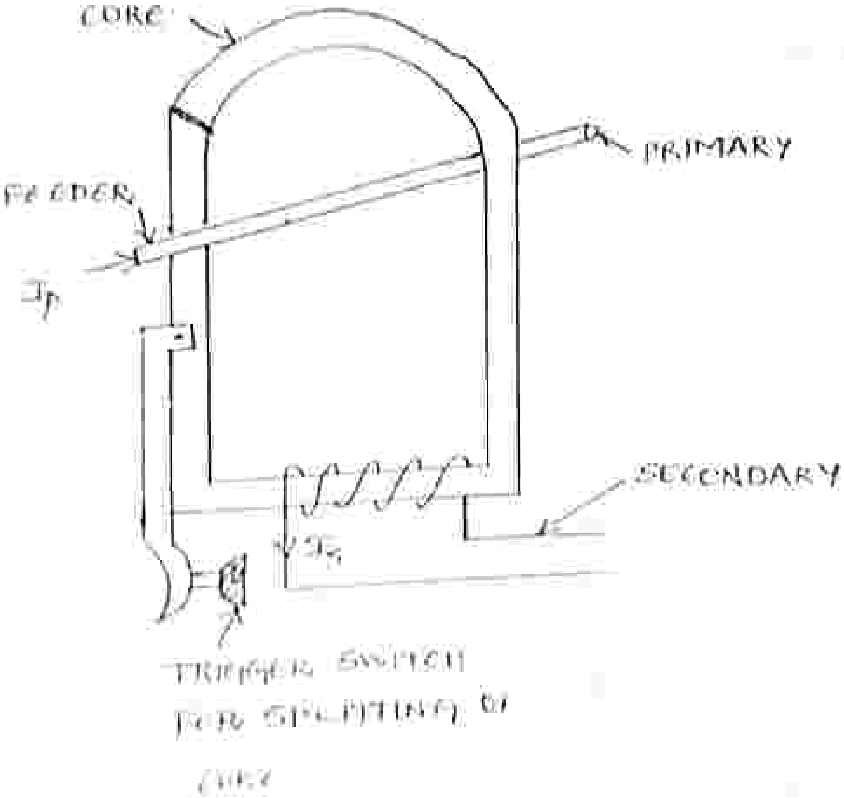
* The smallest full scale range on such clamp on ammeters is 6A.

* The accuracy is within 3% of full scale with the conductor in a central position in the core.

* The instrument can be operated by one hand. It can be used in ac circuits only.

* The special feature is that it can be used instantaneously for measurement of current in a current carrying conductor without interrupting the circuit for connection of ammeter in series with the circuit.


Movable JAW of
Clamp on core
CURRENT
CARRYING
CONDUCTOR
MECHANISM FOR
OPENING
CLAMP-ON CORE
SECONDARY
WINDING
RECTIFIER
D' ARSONVAL MOVEMENT


CORE
PRIMARY
FEEDER
SECONDARY
TRIGGER SWITCH
FOR SPLITTING OF
CORE

Galvanometer Constants

Displacement Constant: Deflecting couple $C_d = NB \cdot l r\, i$

where, N is the no. of turns, B → magnetic field strength

i → current, l → coil length, r → coil width.

Area = $l \times r$

$C_d = NBiA$

$C_d = Gi$

where, G → galvanometer constant.

Constant of Inertia: It is proportional to the angular acceleration.

$$J \cdot \frac{d^2\theta}{dt^2}$$

Damping Constant: This is proportional to the angular velocity.

$$D \cdot \frac{d\theta}{dt}$$

Control Constant:

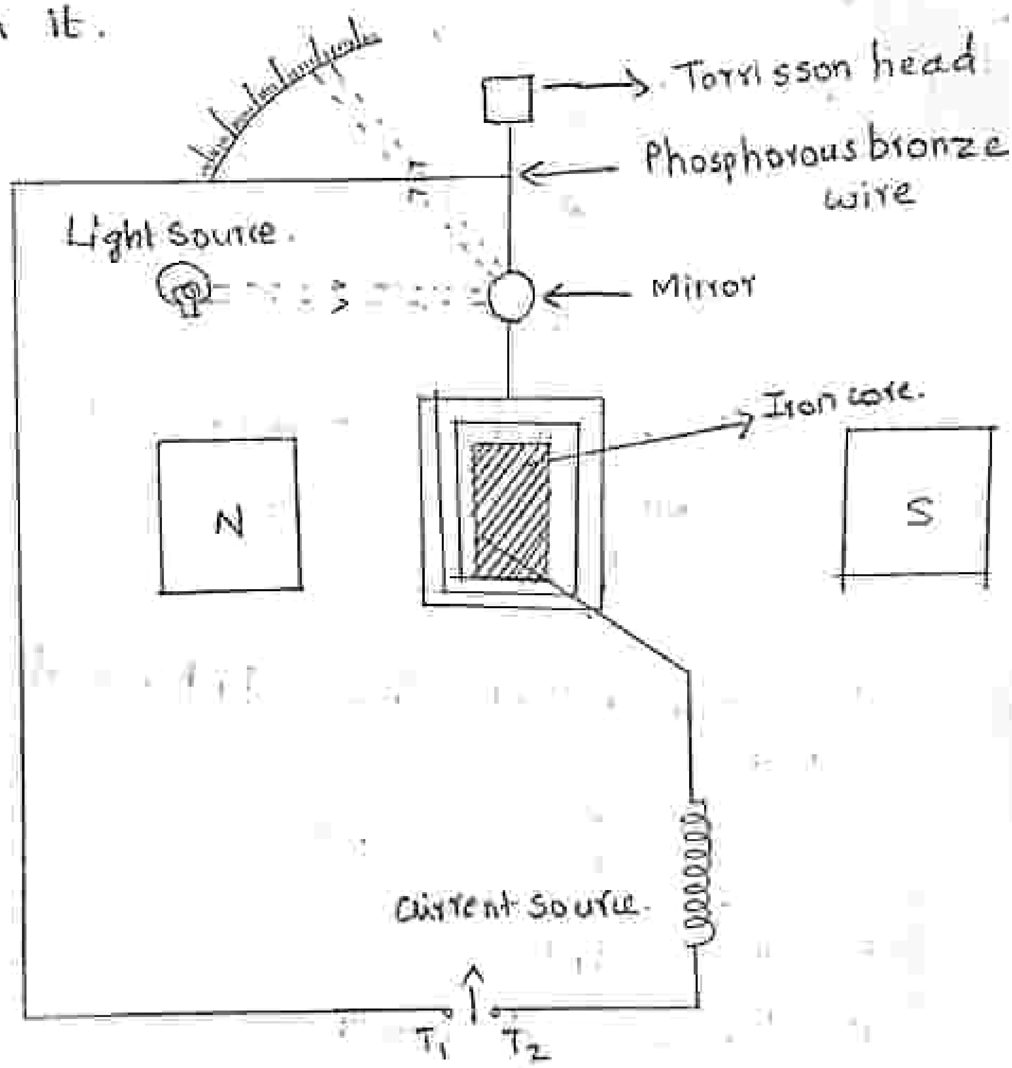
It is due to elasticity of the suspension and it is proportional to displacement: $C \cdot d\theta$ C → Controlling constant.

Hence, the equation of motion is,

$$J \frac{d^2\theta}{dt^2} + D \cdot \frac{d\theta}{dt} + C \cdot d\theta = Gi$$

Ballistic Galvanometer.

This galvanometer is used for estimating the q of charge flowing through it. The deflection of coil is directly proportional to the charge passing through it.



The ballistic galvanometer consists of a Cu wire which is wound on a non-conducting frame. The phosphorous bronze wire suspends the coil between the north pole and south poles of a magnet.

~~ballistic Galvanometer consist of a ... wire which is wound in a non-conducting frame. The Phosphorous bronze wire suspends the coil b/w the north and south poles of a magnet.~~

For increasing the magnetic flux the iron core is placed within the coil. The lower portion of the coil, connects with the spring.

The spring provides the controlling torque to the coil.

It works on the principle that, when a current carrying coil is placed in a magnetic field, it experiences a torque.

The 1st deflection of the moving system of the galvanometer is proportional to the quantity of electricity, which has already pass through it and the change of flux producing it.

The discharge of electricity through the galvanometer, should be completed before the moving system starts to move.

This measurement can be done, only if the whole time, taken for a charge to pass through the instrument is very short.

To get the 1st deflection of maximum amplitude, the ballistic galvanometer is usually lightly damped and the galvanometer is made to have large moment of inertia by attaching small vanes to its moving system.

Principle

During the actual motion, electricity is not present the equation of motion is $a\frac{d^2\theta}{dt^2} + b\frac{d\theta}{dt} + c\,d\theta =$

where, a → is the moment of inertia

b → damping constant

c → Controlling constant.

The solution of this differential equation is of the form;

$$\theta = Ae^{m_1 t} + Be^{m_2 t}$$

A, B → Constants.

m_1, m_2 → Roots of the quadratic equation

$$= \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

As damping constant is very small $b^2 - 4ac$ term is negative and the roots are imaginary in nature. The solution of this differential equation having complex conjugate roots is damped sinusoidal oscillations ie,

$$\theta = e^{-bt/2a}\, b \sin\left(\frac{\sqrt{4ac - b^2}}{2a}\, t + \alpha\right)$$

From the ~~sinusoidal~~ initial conditions.

ie, $t = 0$, $\theta = 0$ & $\alpha = 0$,

$$\theta = e^{-bt/2a}\, b \sin\left(\sqrt{\frac{c}{a}}\, t\right) \quad \text{—— (1)}$$

The deflecting torque is G_i

$$G_i = a\frac{d^2\theta}{dt^2}$$

$$\int_0^{\tau} G_i \cdot dt = \int_0^{\tau} a \frac{d^2\theta}{dt^2} dt$$

$$GQ = a \cdot \frac{d\theta}{dt}$$

$$\frac{d\theta}{dt} = \frac{GQ}{a} \quad \text{—— (2)}$$

Now, diff equn (1).

$$\frac{d\theta}{dt} = \frac{-b}{2a} e^{-bt/2a} b \sin\left(\sqrt{\frac{c}{a}}\, t\right) + e^{-bt/2a} b \cos\left(\sqrt{\frac{c}{a}}\, t\right)\sqrt{\frac{c}{a}}$$

The time period is very small ie, $t=0$.

$$\frac{d\theta}{dt} = b\sqrt{\frac{c}{a}} \quad \text{—— (3)}$$

From (2) & (3)

$$b\sqrt{\frac{c}{a}} = \frac{GQ}{a}$$

$$b = \frac{G}{a}\sqrt{\frac{a}{c}} \cdot Q$$

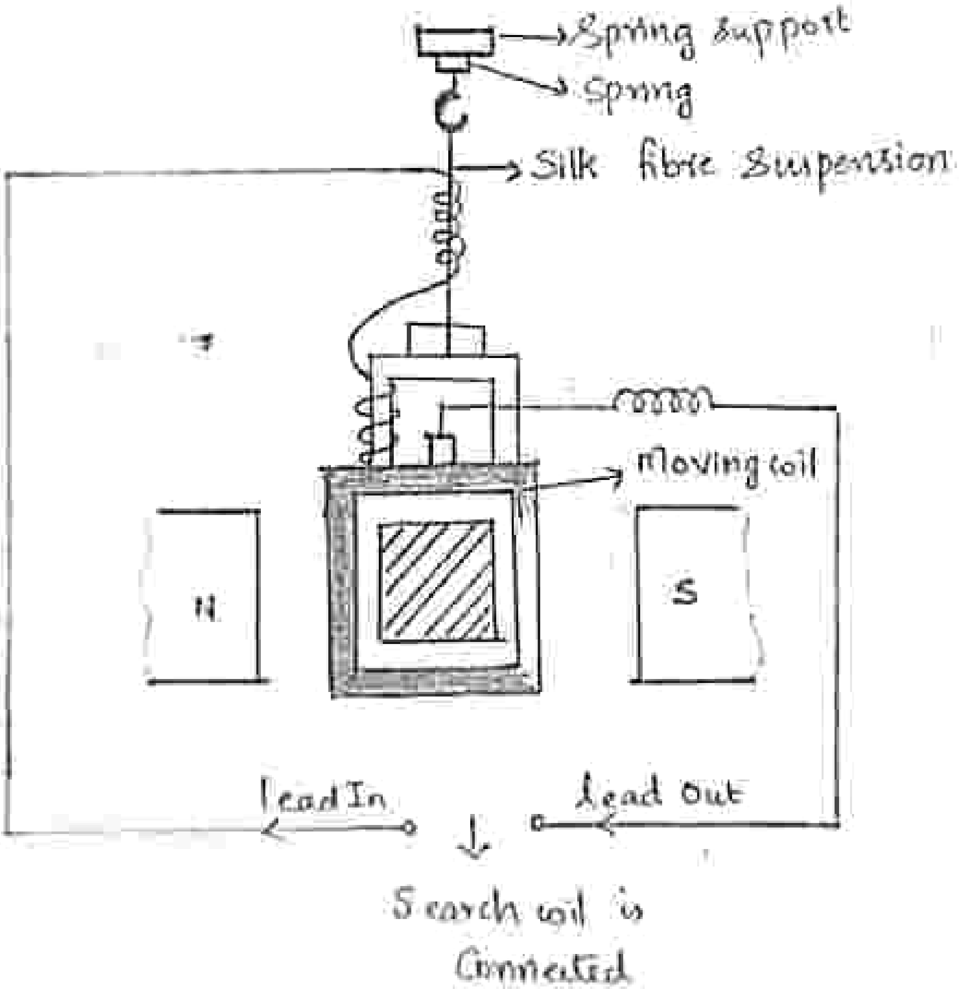
Substitute the value of b in (1)

$$\theta = e^{-bt/2a}\left[\frac{G}{a}\sqrt{\frac{a}{c}}\, Q\right] \sin\left[\sqrt{\frac{c}{a}}\, t\right]$$

It shows that the deflection of the ballistic galvanometer is proportional to the charge Q and is oscillating in [illegible] nature.

02/18

FLUX METER / Grassot Flux meter



It is a special type of ballistic galvanometer. It is provided with very small controlling torque and heavy eddy electromagnetic damping.

It consists of a moving coil of small cross section suspended by means of a single silk thread, from a spring support. The moving coil hangs within the air gaps of a permanent magnet system

Thin silver strip spirals are used to lead the current in and out of the coil.

As a result of this construction, the controlling torque is reduced to a minimum value

The instrument is provided with the pointer attached to the moving system and the scale graduated in weber turns.

When the instrument terminals are connected to a search coil and the flux linking with the search coil is changed. The moving system of the flux meter is deflected and rotates through an angle which depends upon the change in flux turns.

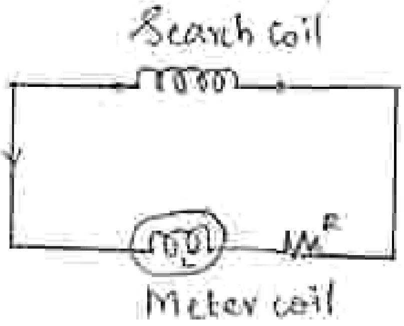
The instrument coil rotates during the whole period of flux change

As soon as the flux change linking with the search coil is stopped, the moving coil stops because of high electromagnetic damping.

If the controlling torque is completely absent the coil remains in the deflected position, indefinitely, but practically, it comes back to zero, very slowly.

The reading may be obtained by observing the difference in deflections at the beginning and at the end of the change in flux without waiting for the pointer to return to zero.

PRINCIPLE



R & L → Total resistance and inductance of the circuit consisting of the meter coil and the search coil. Here, the resistance of the coil is very less and inductance is made large

N → No. of turns in the search coil

ϕ → Flux linking with the search coil.

i → instantaneous current flowing in the circuit.

The emf induced in the search coil due to the change in linking flux at any instant, is,

$$e = N \frac{d\phi}{dt}$$

The emf induced in the flux meter coil due to the movement of coil in the permanent magnet field at any instant is,

$$e_b = K \cdot \frac{d\theta}{dt} \quad \text{(back emf)}.$$

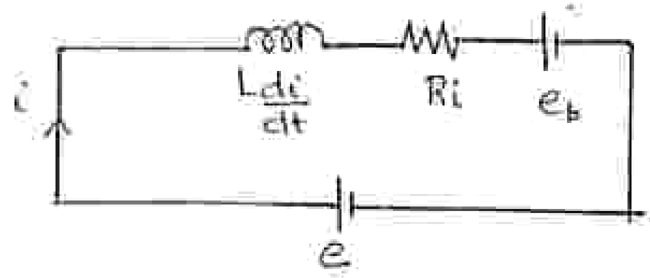
where K → is the constant of the flux meter coil and

$\frac{d\theta}{dt}$ → is the angular velocity of the flux meter coil.

The emf due to the inductance in the circuit,

$$e = L \frac{di}{dt}$$

The voltage drop in the resistance of the circuit = Ri



$$e = N \frac{d\phi}{dt}$$

$$e_b = K \cdot \frac{d\theta}{dt}$$

$$e - L \cdot \frac{di}{dt} - Ri - e_b = 0$$

$$e = e_b + L \cdot \frac{di}{dt} + Ri$$

Since R & i is very less, it can be neglected.

$$e = e_b + L \cdot \frac{di}{dt}$$

$$N \cdot \frac{d\phi}{dt} = K \cdot \frac{d\theta}{dt} + L \cdot \frac{di}{dt}$$

T → time taken for flux change.

$$\int_0^T N \cdot \frac{d\phi}{dt} \cdot dt = \int_0^T K \cdot \frac{d\theta}{dt} \, dt + \int_0^T L \cdot \frac{di}{dt} \cdot dt$$

Let,

ϕ_1 & ϕ_2 → flux density linking with the search coil.

i_1 & i_2 → currents flowing through the search coil circuit

θ_1 & θ_2 → deflection of the flux meter.

$$\int_{\phi_1}^{\phi_2} N \cdot d\phi = \int_{\theta_1}^{\theta_2} K \cdot d\theta + \int_{i_1}^{i_2} L \cdot di$$

$$N(\phi_2 - \phi_1) = K(\theta_2 - \theta_1) + L(i_2 - i_1)$$

Since, current value is very less, $L(i_2 - i_1)$ is neglected

$$N(\phi_2 - \phi_1) = K(\theta_2 - \theta_1)$$

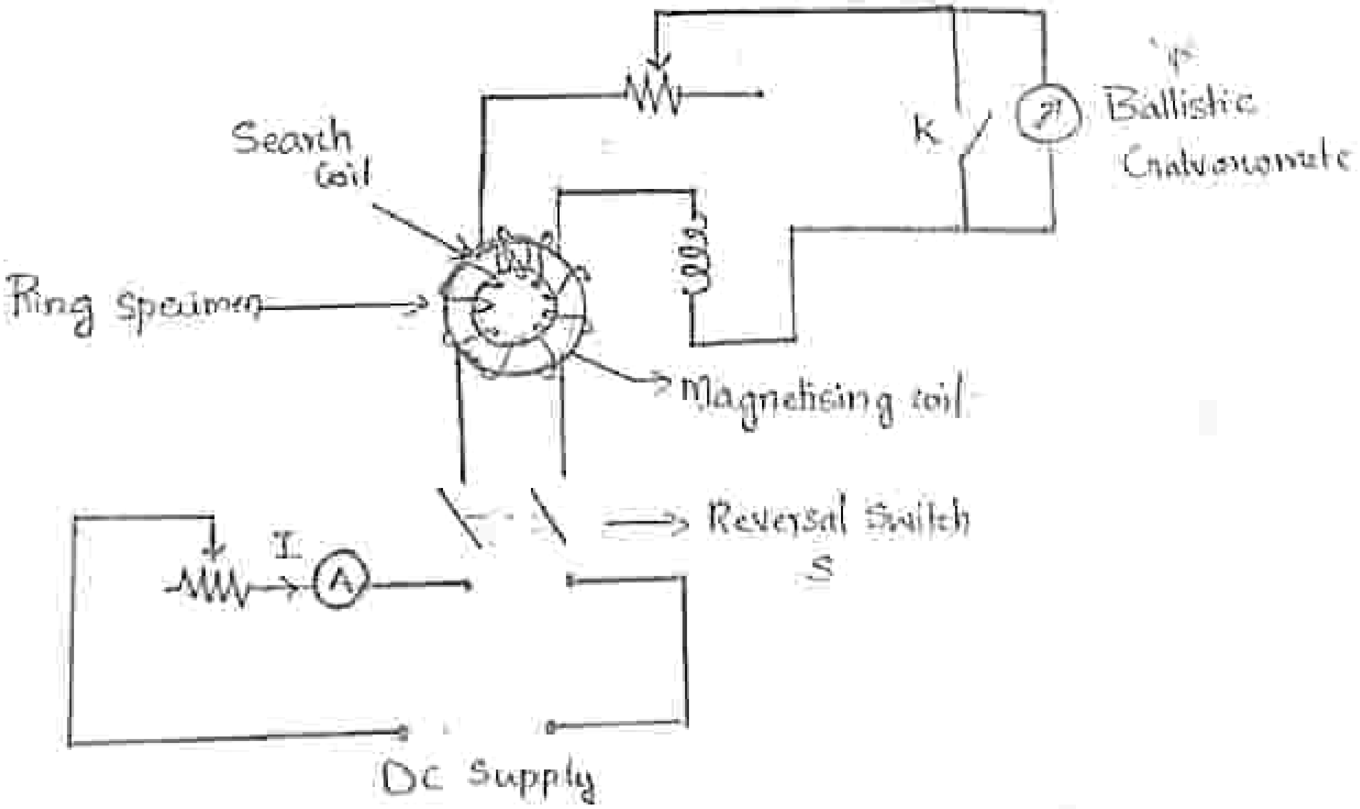
$$\theta_2 - \theta_1 = \frac{N}{K}(\phi_2 - \phi_1)$$

$$\boxed{\theta_2 - \theta_1 \propto N(\phi_2 - \phi_1)}$$

∴ The deflection is proportional to the flux linkage turns.

Determination of B-H Curve:

1) Method of Reversals.



A ring specimen with known dimensions is taken for test. A thin tape is wound on the ring. The search coil is wound over the tape. Another layer of tape is wound on the search coil. Then the magnetising winding is wound uniformly on the specimen.

PROCEDURE

The complete specimen is demagnetised before the test using the variable resistance, the magnetising current is adjusted to its lower value at the begining of the test. The ballistic galvanometer switch K is closed and reversing switch 'S' is thrown backward and forward for about 20 times. This brings the iron specimen into a reproducable cyclic magnetic state.

Measure the value of I from the ammeter and calculate

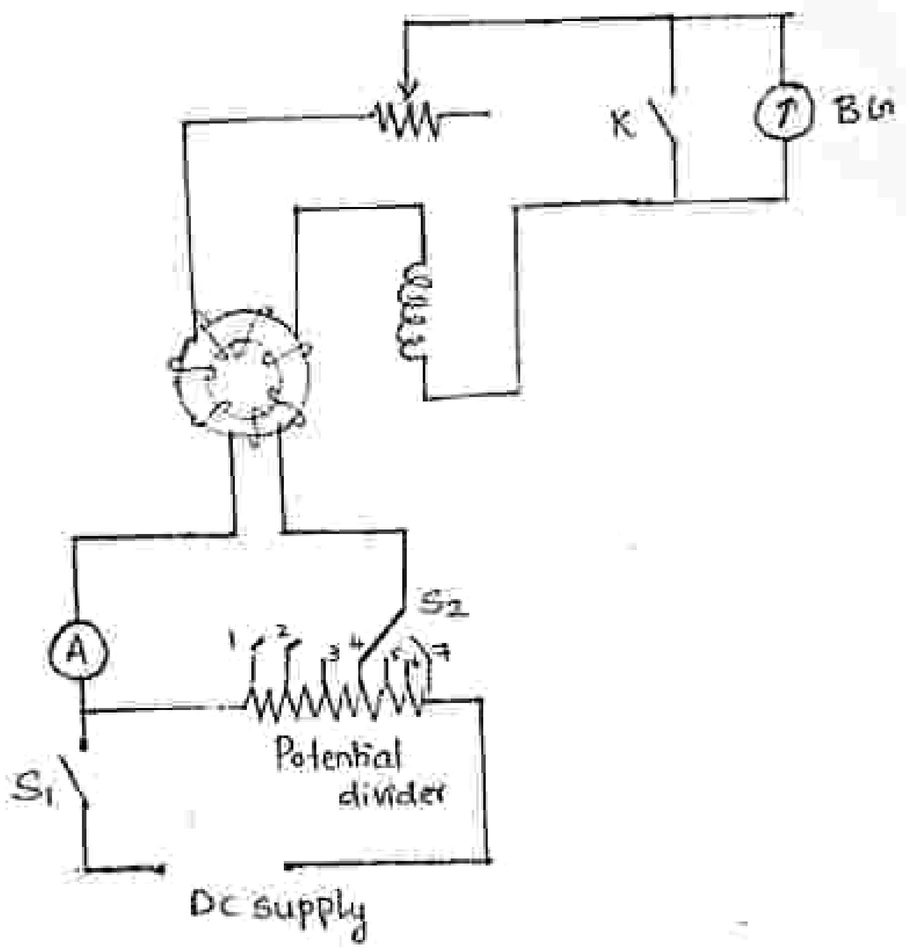
$$H_1 = \frac{N I_1}{l}$$

The galvanometer key is now open and the flux in the specimen corresponding to this value of H_1 is measured from the deflection of the ballistic galvanometer.

Flux density ; $B = \frac{\phi}{A}$

The procedure is repeated for different values of H, by increasing H upto the maximum value. The graph of B against H gives the required B-H curve for the specimen.

2) Step by step method.



In this method reversal of magnetising current is not used. The magnetising current in the winding is supplied through a potential divider. The potential divider has a no tappings. Tappings are arranged in a such a way that the magnetising force H increases in suitable no of step upto the required maximum value.

PROCEDURE

1. The specimen is completely demagnetised before starting the test. The switch S_1 is closed with switch S_2 at

tapping 1. Due to this, there will be some change in the flux and hence flux density increases from zero to B_1. This value can be obtained by observing the deflection of the ballistic galvanometer.

$$B_1 = \frac{\phi_1}{A}$$

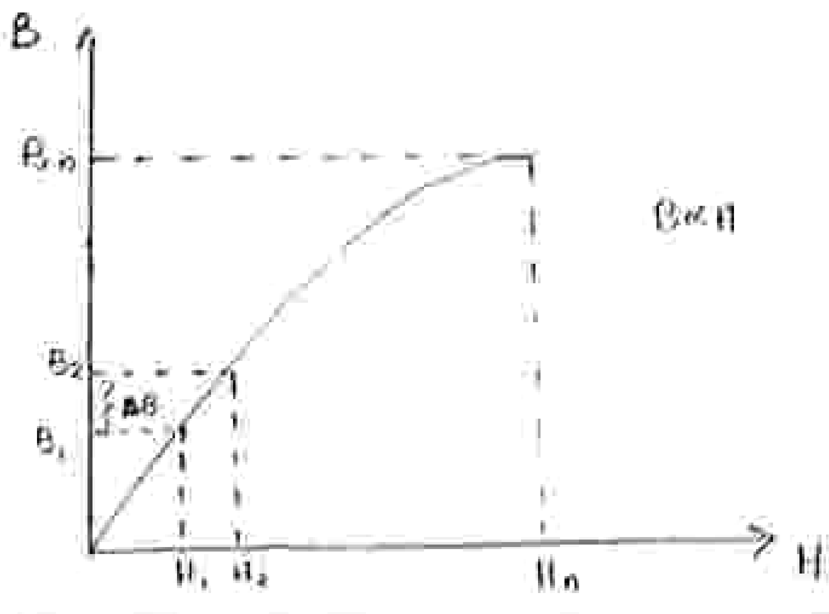
2. Record the value of the corresponding magnetising current and calculate, $H_1 = \frac{N_1 I_1}{l}$

3. The switch S_2 is instantaneously change to tapping 2 which increases the magnetising force to H_2.

4. Due to this, flux density increases by ΔB. This can be observed from the galvanometer. Hence, $B_2 = B_1 + \Delta B$

5. The procedure is repeated for various tappings, till the maximum value of H is achieved.

The graph of B against H is plotted and this is the B-H curve for the specimen under test.



5/3/2018 Determination of hysteresis loop.

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Two methods are used :-

(1) step by step method.

(2) Method of reversals.

Step by step method:

1. Follow the same procedure as the determination of B-H curve, until H reaches maximum.

2. Reduce the magnetising current in steps to zero by movi the tapping to 7, 6, 5, 4, 3, 2, 1.

3. After magnetising current reaches to Zero, reverse the supp of the potential divider to obtain -ve H.

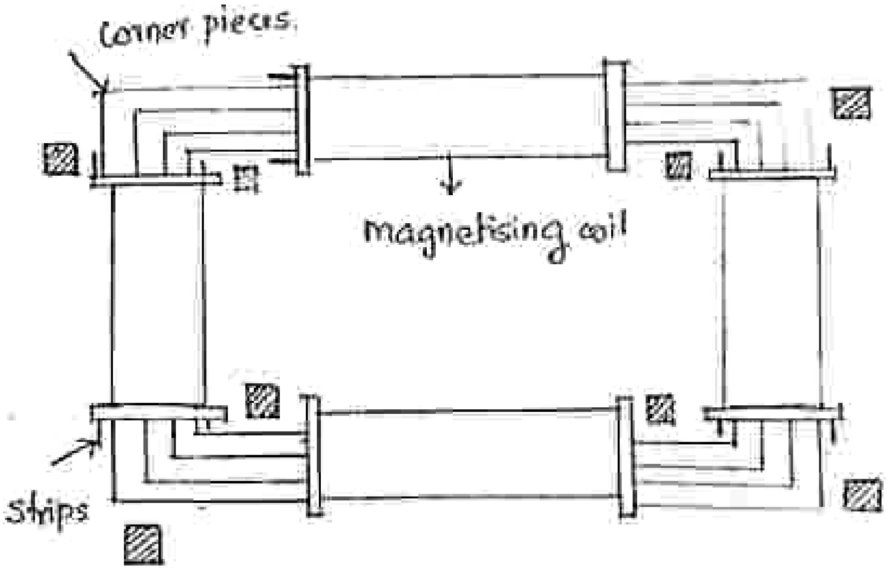
4. Move the switch S_2 up in the range again 1, 2, 3, 4. Note down the values of B and H and draw the loop

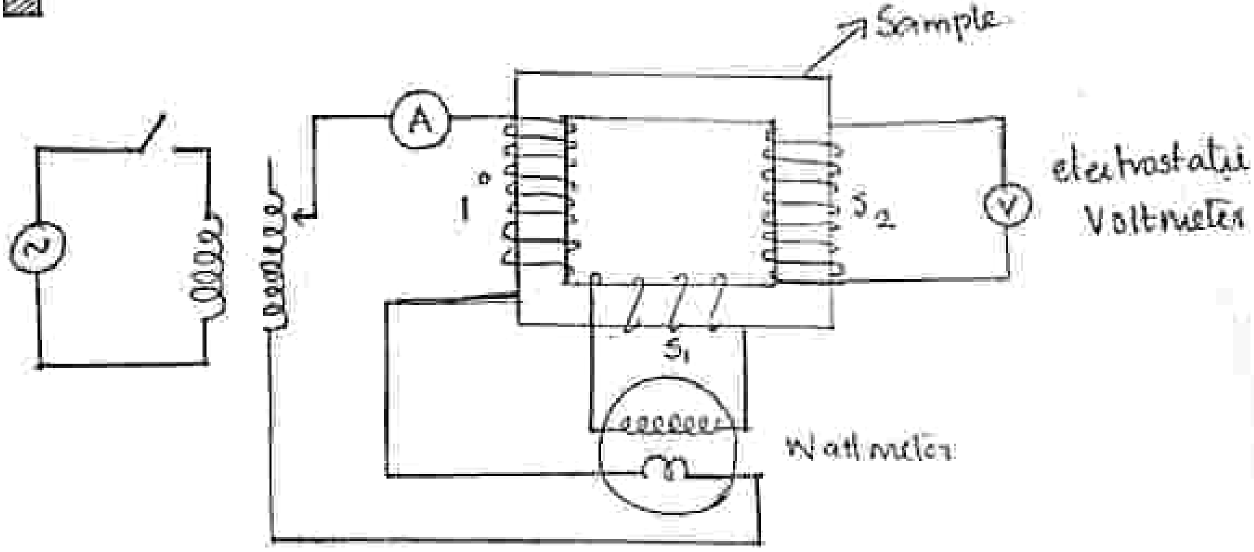
Method of reversals.

The iron specimen is passed through the remaining cycle of magnetisation back of flux density B_m. The v of this $+B_m$ is noted, the cycle of magnetisation is preserved, and found the B-H curve.

MEASUREMENT OF IRON LOSSES:

Lloyd - Fisher Method:





1. This is the most commonly used method of forming magnetic square to findout the iron losses.
2. The material is cut half in the direction of rolling of the sheet in the manufacter and half in the ⊥r

direction to this direction.

3. The strips are about 250 mm long and 50-60 mm wide and the total weight of this sample is about 2kg.

4. They are built up into 4 bundles and assemble to form the Complete magnetic circuit with the help of bend corner pieces.

5. These corner pieces should be of same material of the strips

6. The primary winding formed by connecting 4 similar magnetising coils in series, is connected to an alternator through autotransformer in series with the current coil of the wattmeter.
The alternator should be able to produce a nearly sinusoidal emf.

7. There are 2 single layer 2° coils, made from thin wire under each magnetising coil and of same no. of turns under each magnetising co... across one of the 2° coils the potential coil of the wattmeter is connected and across the other coil an electrostatic Voltmeter is connected.

8. The cross sectional area and the weight of the specimen are determined before assembling.

9. The supply frequency is adjusted to a correct value, the magnetising current is adjusted to give required value of maximum flux density (Bmax) and the readings of voltmeter and wattmeter are noted.

$$\text{Form factor} = \frac{\text{rms Value}}{\text{Average value}}$$

rms of value of emf induced in Secondary winding S_2 is measured by the voltmeter. ie,

$$E_{rms} = k_f(E_{avg})$$

$k_f = 1.11$

$E_{avg} = 4.44 f \phi N_2$

$$= k_f(4 \times f \phi N_2) \quad \text{—— (1)}$$

$$= k_f(4 f B_{max} A_s N_2) \text{ Volts} \quad \text{—— (ii)}$$

Let A_c be the cross section of the coil and A_s Crosssection of the specimen.

Total flux with the coil, $\phi = B_{max} A_c$

$$= B_{max} A_s + B_{max}(A_c - A_s)$$

$$(2) \quad \text{——} \quad \phi = B_{max} A_s + \mu H_{max}(A_c - A_s)$$

Sub (2) in (1)

$$E_{rms} = k_f\left(4 f N_2 \left[B_{max} A_s + \mu H_{max}(A_c - A_s)\right]\right)$$

H_{max} can be obtained from the permeability curve of the sample. Voltage applied to the pressure coil circuit

$$V = I_p R_p$$

Induced emf in the 2° winding, S_2;

$$E = I_p(R_p + R_s)$$

Total Power loss = Iron loss + copper loss

$$= \frac{W \cdot E}{V} = \frac{W I_p(R_p + R_s)}{I_p R_p}$$

$$= \frac{W(R_p + R_s)}{R_p}$$

$$= W\left[1 + \frac{R_s}{R_p}\right]$$

Total Copper loss in both R_p and R_s,

$$= I_p^2 (R_p + R_s)$$

$$= \frac{E^2}{(R_p + R_s)}$$

$E \cdot I$

$\frac{WE}{V} = I_p^2 (R_p + R_s)$

Actual Iron loss,

$$P_i = W\left[1 + \frac{R_s}{R_p}\right] - \frac{E^2}{(R_p + R_s)}$$

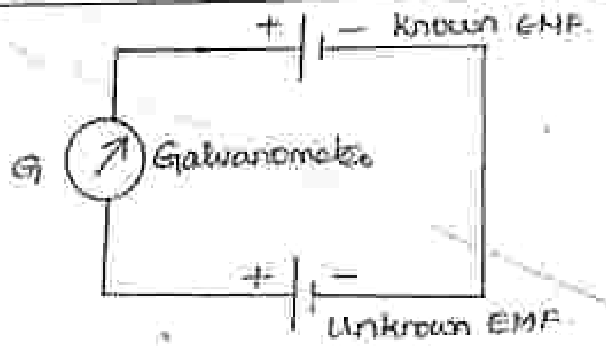
MODULE - 5

POTENTIOMETER :-

A potentiometer is an insturment designed to measure an unknown voltage by comparing it with a known voltage.

Measurements using comparison methods are capable of a high degree of accuracy because the result obtained does not only depend upon on the actual deflection of the pointer, but only upon the accuracy with which the voltage of the reference source is known.

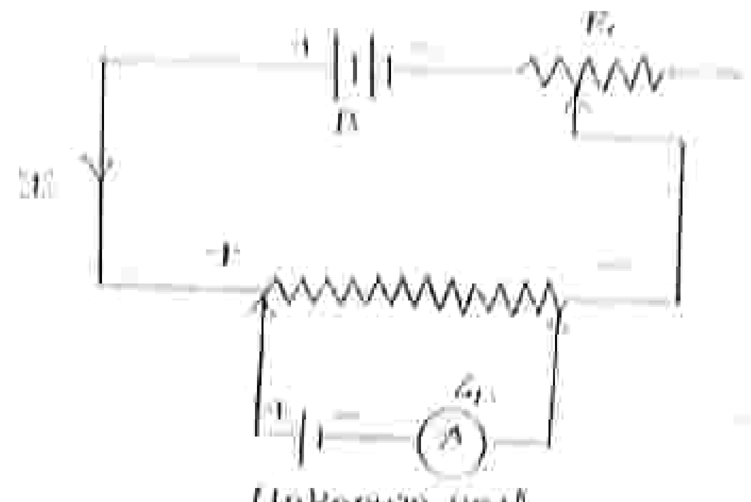
PRINCIPLE OF POTENTIOMETER :-



Without potentiometer.

The potentiometer works on the principle of opposing the unknown emf by a known emf with the -ve terminals of two emfs connected together and also the +ve terminals connected together through a galvanometer. The Galvanometer gives no deflection if the two emfs are equal. But using this arrangement, the known emf cannot be varied to give many values. Hence another circuit which includes a potentiometer is used.

With Potentiometer :-

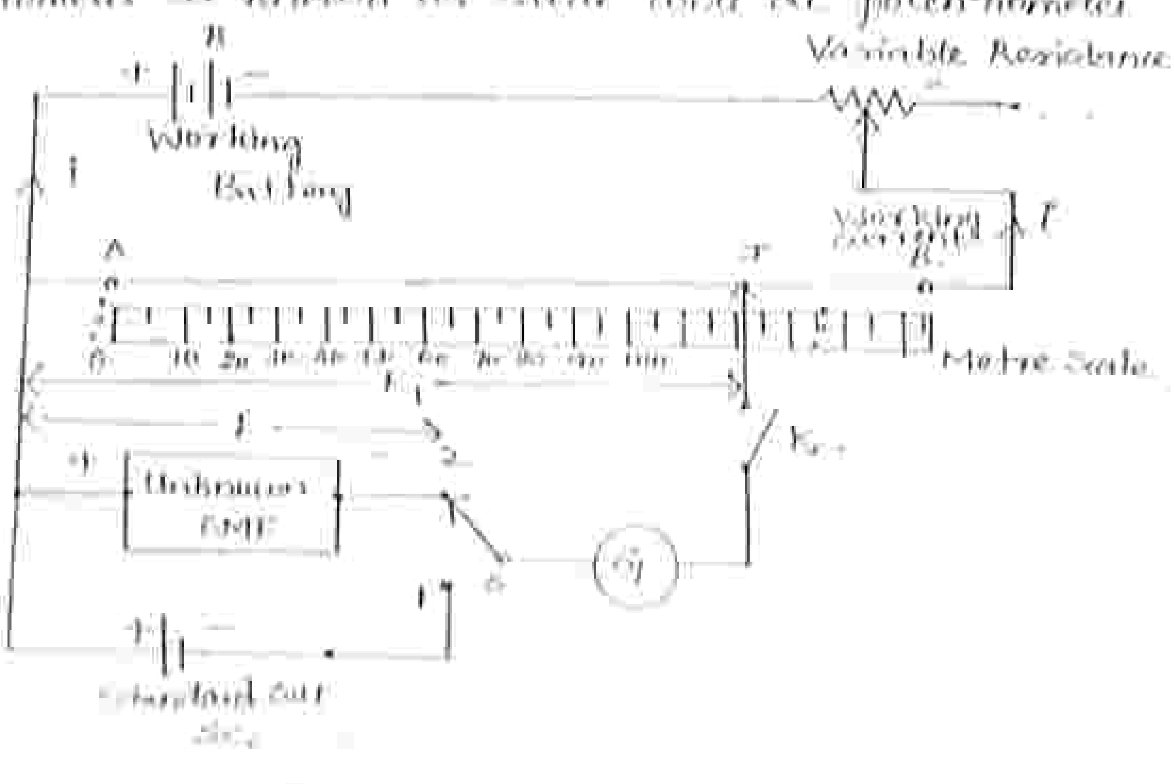


Unknown emf.

In this arrangement, an unknown emf is connected in parallel with and in opposition to a voltage drop in the resistor. In this arrangement, it is very simple to vary the current in the resistor and thus obtain, with very fine adjustment, any desired voltage.

DC POTENTIOMETERS :-

The simplest and basic type of dc potentiometer is known as slide wire dc poten-tiometer



With switch S in position 1, and the galvanometer key is open, the battery supplies the working current through rheostat R_1 and the slide wire. This current can be varied by changing the rheostat setting. Thus full resistance R_2 of the slide wire can be found out.

To find the unknown voltage E, the sliding contact should be in a position such that the galvanometer shows null condition when the galvanometer key, K_1 is closed.

Zero deflection means than $E_1 = E$.

E_1 is the voltage drop across AJ.

Hence if E_1 is found out, E can be found out.

For L ~~length~~ length = R_2 resistance.

l length AJ $= \frac{R_2}{L} \times l$. resistance.

Hence $E_1 = \left(\frac{R_2}{L} \times l\right) \times$ working current.

AC POTENTIOMETERS :-

The d.c potentiometer is an accurate and versatile instrument and thus it is possible to use the same principle for measurement of alternating currents and voltages. The principle of alternating current potentiometer is the same as that of the direct current potentiometer.

The difference of ac and dc potentiometer is that in dc potentiometer only the magnitudes of the unknown emf and potentiometer voltage drop have to be made equal to obtain balance, whereas in the ac instruments both magnitudes and phases of the emf and voltage drop has to be same to obtain balance. Thus an ordinary dc potentiometer cannot be used for ac measurements and certain modifications have to be made so that it may be used for ac work.

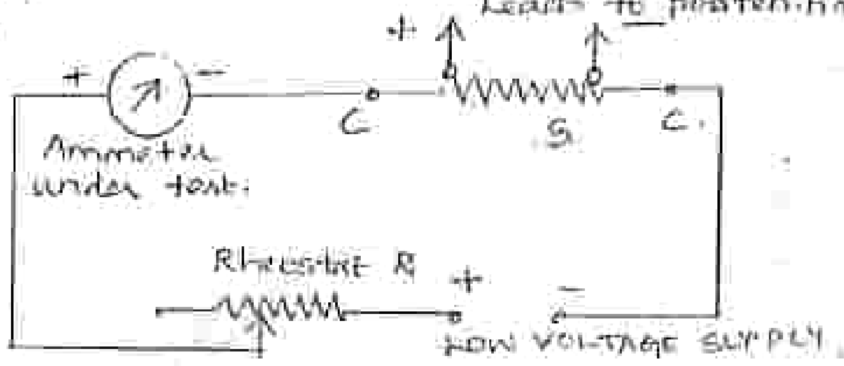
CALIBRATION OF AMMETER USING POTENTIOMETER :-

The ammeter to be calibrated is connected in series with a variable resistance R and a standard resistance S. S should be of such a magnitude that with the current to be passed through it, the voltage drop across it does not exceed the range of potentiometer. Variable resistance R is included in the circuit to vary the magnitude of current flowing through the ammeter and standard S.

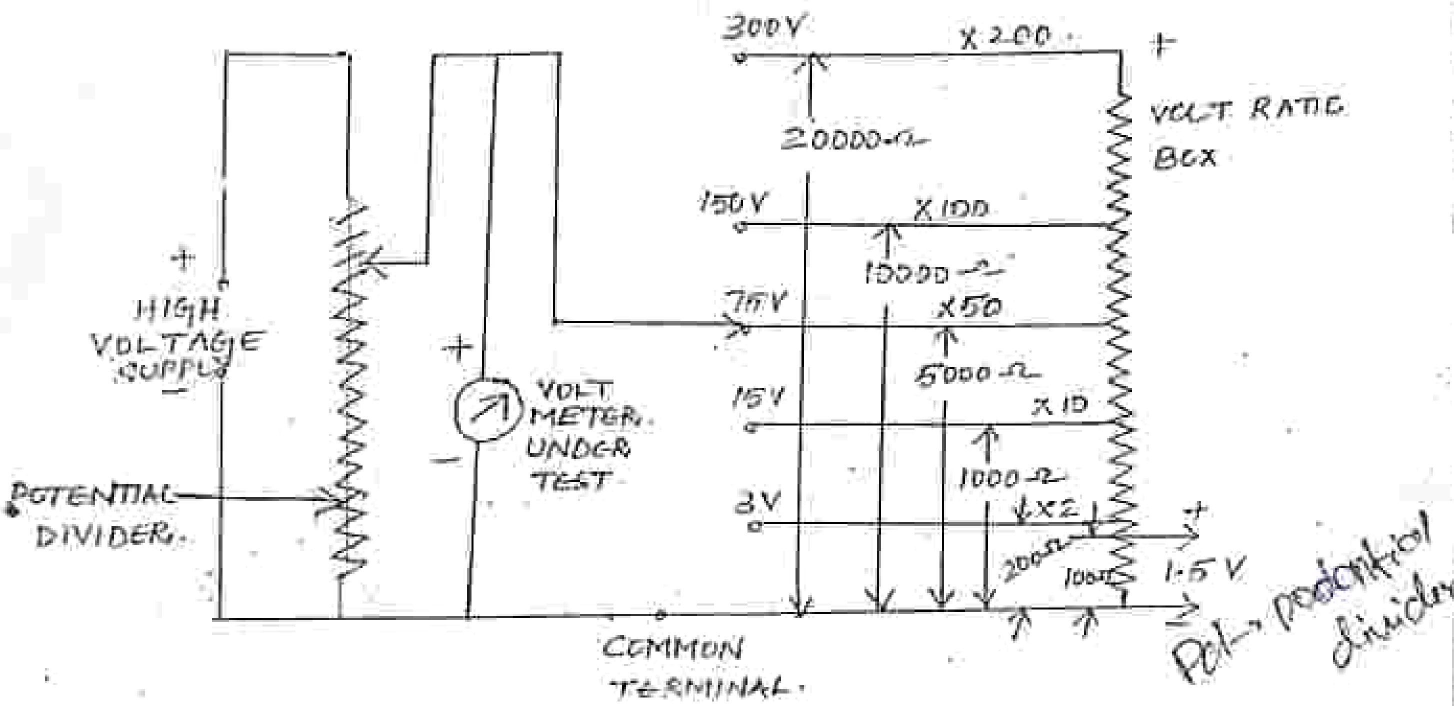
The voltage drop across standard resistance S is measured on the potentiometer.

$$\frac{\text{Voltage drop across the standard resistance}}{\text{Standard resistance}} = \text{Value of current through the ammeter}$$

Thus current reading is compared with the reading of the ammeter under test. Many readings are taken and finally calibration can be done.



CALIBRATION OF VOLTMETER USING POTENTIOMETER :-



* For calibration of voltmeter, a potential divider of high resistance is connected across high voltage (say 250 V) dc supply main.

* The voltmeter under calibiation is connected across this potential divider. The p.d across the voltmeter can be varied.

* The volt ratio box is connected in parallel with voltmeter under calibration to reduce the voltage across them to a value, which is within the range of potentiometer.

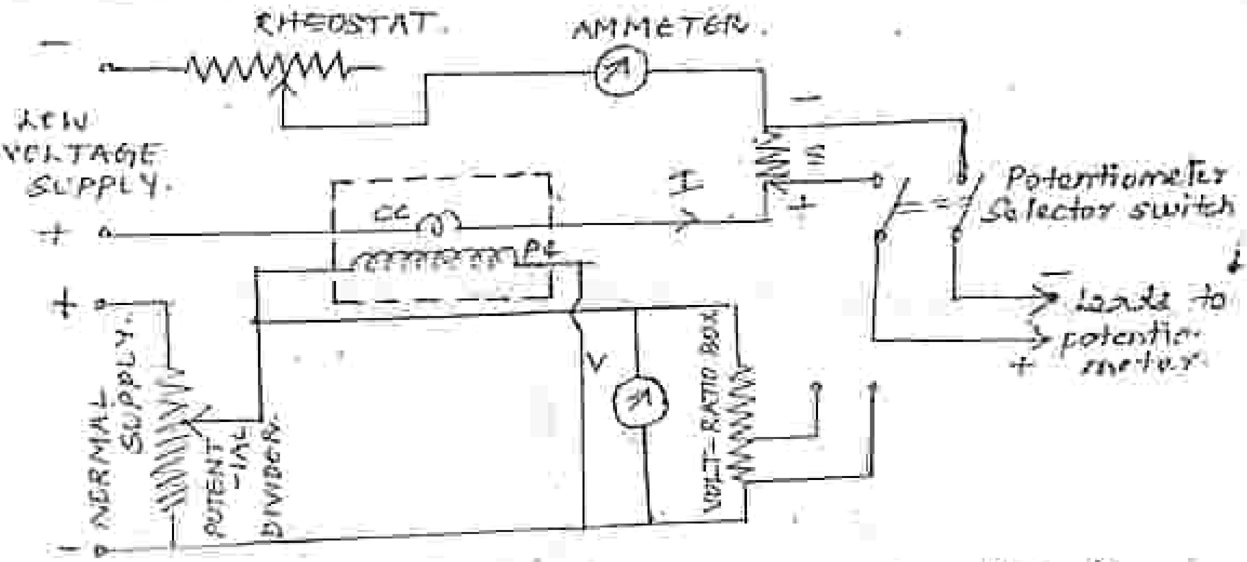
* Now this reduced potential difference is measured on the potentiometer.

* The potential difference measured on the potentiometer multiplied by the ratio of volt-ratio box gives the actual potential difference across the voltmeter under calibration.

* Then this p.d is compared with the instrument reading.

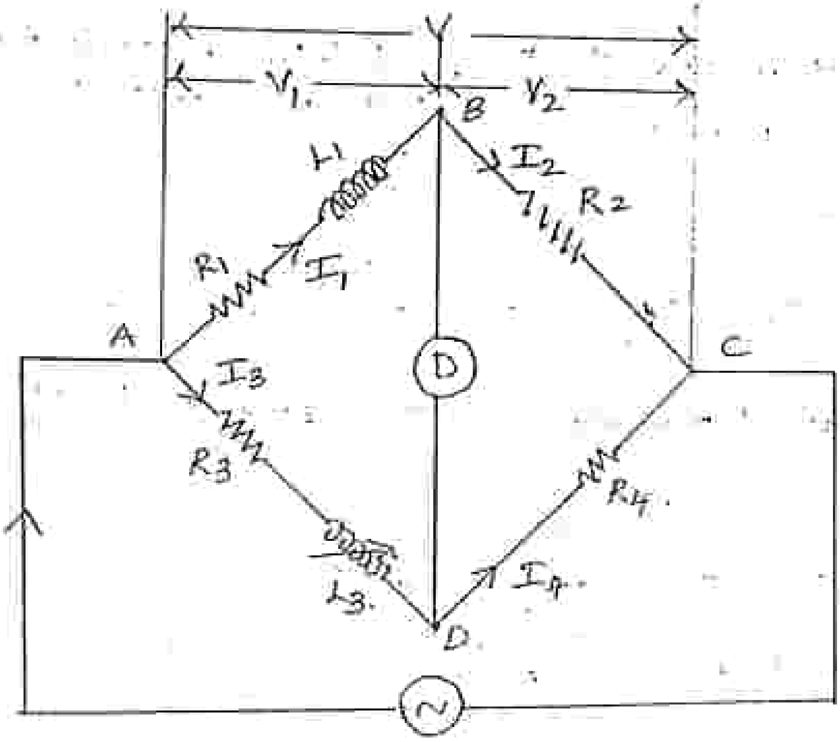
* The voltage across the voltmeter is changed by varying the position of the sliding contact on potential divider and this process is repeated for various values of potential difference across the voltmeter.

CALIBRATION OF WATTMETER :-



* The current coil of wattmeter under calibration is supplied from a low voltage supply and potential coil from the normal supply through a potential divider.
* The voltage V across the potential coil and current I through current coil are measured in turn by the potentiometer employing a volt-ratio box and standard resistor.
* The true power is then VI watts and the wattmeter reading may be compared with this value.
* This is a precise method of calibration of wattmeter.

MAXWELL'S BRIDGE :-



* For accurate measurement of medium resistances.
* In this method, unknown inductance is found out by comparing it with a standard self inductance.
* Here L_1 → unknown self inductance of resistor R1.
* L_3 → known variable inductance of resistor R_3 whose resistance is constant.
* R_2 + R_4 → pure resistances.
* D → detector.
* The bridge is balanced by varying L_3 and one of the resistances R_2 + R_4.
* When the bridge is balanced, the current flowing through the detector is zero.

and $I_1 = I_2$

$I_3 = I_4$.

Potential difference across arm AB = Potential difference across arm AD.

$$I_1 Z_1 = I_3 Z_3 = V_1.$$

(or) $I_1(R_1 + jX_4) = I_3(R_3 + jX_3) = V_1$. ——— ①

and Potential difference across arm BC = Potential difference across arm CD.

$$I_2 R_2 = I_4 R_4 = V_2.$$

$$I_1 R_2 = I_3 \cdot R_4 \quad \text{——— ②}$$

$$\frac{①}{②} \Rightarrow \frac{I_1(R_1 + jX_4)}{I_1 R_2} = \frac{I_3(R_3 + jX_3)}{I_3 R_4}$$

$$\frac{R_1}{R_2} + \frac{jX_L}{R_2} = \frac{R_3}{R_4} + \frac{jX_3}{R_4}.$$

Equating the real and imaginary parts,

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}.$$

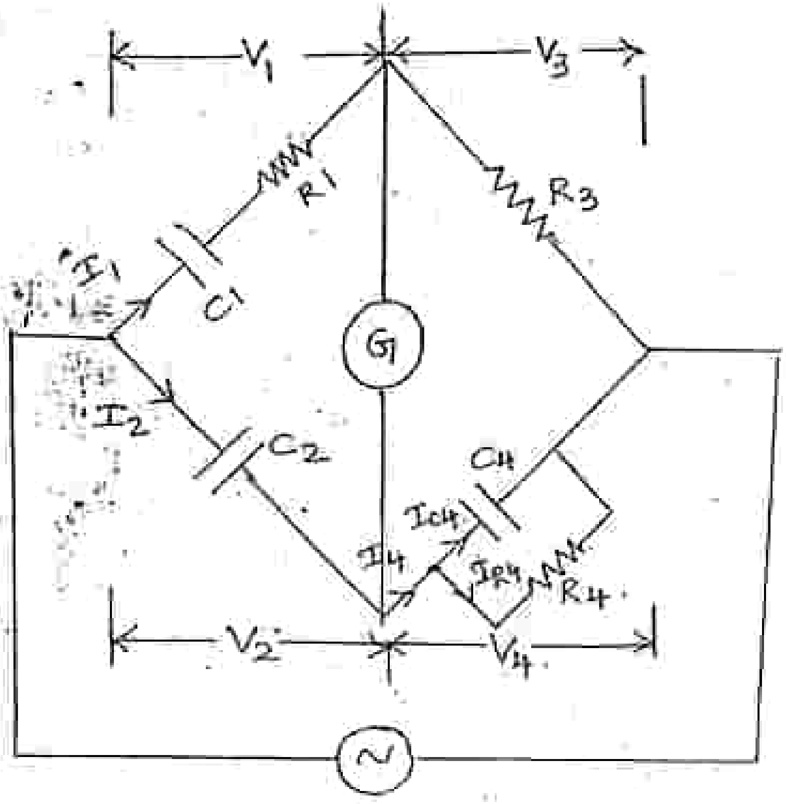
$$\boxed{R_1 = R_2 \frac{R_3}{R_4}}$$

and $\frac{X_4}{R_2} = \frac{X_3}{R_4}$.

$$\frac{\omega L_1}{R_2} = \frac{\omega L_3}{R_4} \qquad \boxed{L_4 = R_2 \frac{L_3}{R_4}}$$

Thus the value of unknown Self inductance is measured.

SCHERING'S BRIDGE :-



$$Z_1 = R_1 - jX_{C1}$$

$$Z_2 = -jX_{C2}$$

$$Z_3 = R_3$$

$$\frac{1}{Z_4} = \frac{1}{R_4} + \frac{j}{X_{C4}}$$

At balance condition,

$$\frac{Z_1}{Z_2} = \frac{Z_3}{Z_4}$$

$$\frac{(R_1 - jX_{C1})}{-jX_{C2}} = R_3\left(\frac{1}{R_4} + \frac{j}{X_{C4}}\right)$$

(127)

$$\frac{R_1}{-jX_{C2}} + \frac{jX_{C1}}{jX_{C2}} = \frac{R_3}{R_4} + \frac{jR_3}{X_{C4}}$$

$$\frac{jR_1}{X_{C2}} + \frac{X_{C1}}{X_{C2}} = \frac{R_3}{R_4} + \frac{jR_3}{X_{C4}}$$

$$\frac{X_{C1}}{X_{C2}} = \frac{R_3}{R_4}$$

$$\frac{wC_2}{wC_1} = \frac{R_3}{R_4}$$

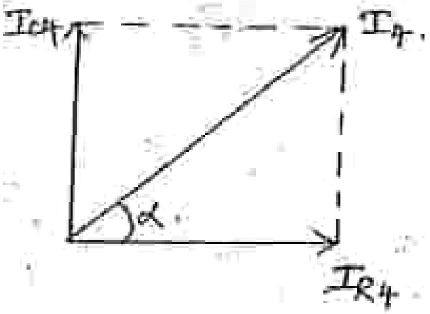
$$\boxed{C_1 = \frac{C_2 R_4}{R_3}}$$

Equating imag. terms,

$$\frac{R_1}{X_{C2}} = \frac{R_3}{X_{C4}}$$

$$wC_2 R_1 = R_3 wC_4$$

$$\therefore \boxed{R_1 = \frac{R_3 C_4}{C_2}}$$



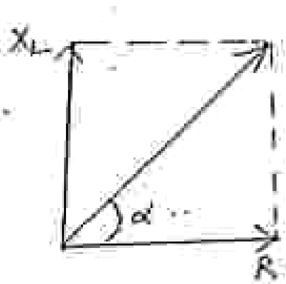
Dissipation factor D is the tangent of the loss angle.

$$Q = \tan\alpha = \frac{I_{C4}}{I_{R4}} = \frac{V_4 \omega C_4}{V_4/R_4} = \omega C_4 R_4.$$

It indicates the quality of a capacitor ie how close the phase angle of a capacitor is to the ideal value of 90°.

When resistance and Inductance in series.

$R + jX_L$.



$$Q = \tan\alpha = \frac{X_L}{R} = \frac{\omega L}{R}.$$

When capacitance and resistance in series,

$$Q = \frac{1}{\omega RC}.$$

The Quality factor of the coil is the time constant of a coil $\tau = \frac{L}{R}$. It is required as the time required for the current to raise to its final steady state value if it is continued rising at its inital state (or) the time taken to reach 0.632 of its final steady state value in RL circuit

WIENS BRIDGE :-

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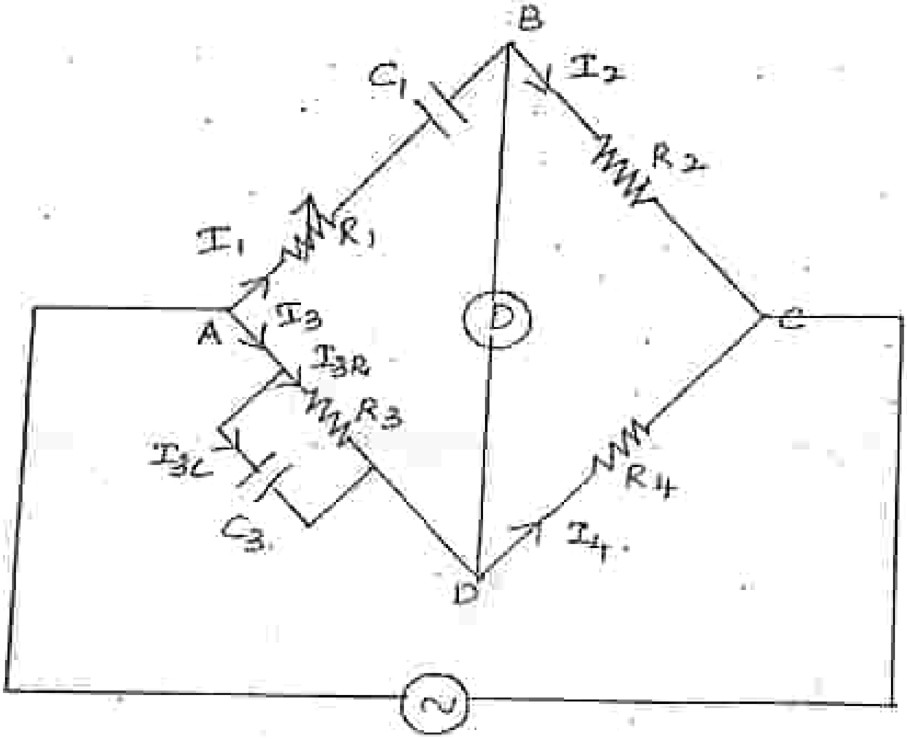


* The Wien's bridge has a series R-C combination in one arm and a parallel combination in the adjoining arm.
* This bridge circuit was widely used in measuring capacitance and capacitor losses, even at high voltages.
* This bridge circuit is frequency sensitive and nowadays it is employed for determination and control of frequency.
* The impedances of Wiens bridge are,

$$Z_1 = R_1 - jX_{C1} = R_1 - \frac{j}{\omega C_1} \; ; \quad Z_2 = R_2$$

$$\frac{1}{Z_3} = \frac{1}{R_3} + \frac{j}{X_{C3}} \; ; \quad Z_4 = R_4.$$

Under balanced conditions of bridge,

$$Z_1 Z_4 = Z_2 Z_3$$

$$\left(R_1 + \frac{1}{j\omega C_1} \right) R_4 = R_2 \left(\frac{R_3}{1+j\omega C_3 R_3} \right)$$

$$\left(R_1 R_4 + \frac{R_4}{j\omega C_1} \right) \left(1 + j\omega C_3 R_3 \right) = R_2 R_3$$

$$R_1 R_4 + j\omega C_3 R_3 R_1 R_4 + \frac{R_4 \times j}{j\omega C_1 \times j} + \frac{R_4 C_3 R_3}{C_1} = R_2 R_3 .$$

Separating real and imaginary parts,

$$R_1 R_4 + \frac{R_4 C_3 R_3}{C_1} = R_2 R_3$$

$$\frac{C_3}{C_1} = \frac{R_2 R_3 - R_1 R_4}{R_4 R_3}$$

$$\boxed{\frac{C_3}{C_1} = \frac{R_2}{R_4} - \frac{R_1}{R_3}}$$

and $\frac{-j R_4}{\omega C_1} + j\omega C_3 R_3 R_1 R_4 = 0$

$$-R_4 + \omega^2 C_1 C_3 R_3 R_1 R_4 = 0$$

$$\omega^2 = \frac{+R_4}{C_1 C_3 R_3 R_1 R_4} \Rightarrow \omega^2 = \frac{+1}{C_1 C_3 R_3 R_1}$$

$$\omega = \frac{1}{\sqrt{C_1 C_3 R_3 R_1}} \qquad f = \frac{\omega}{2\pi}$$

$$\boxed{f = \frac{1}{2\pi \sqrt{C_1 C_3 R_3 R_1}}}$$

In most Wien bridge circuits, the components are chosen such that

(13) $R_1 = R_3 = R$ &

$C_1 = C_3 = C$.

$$\therefore \frac{C_3}{C_4} = \frac{R_2}{R_4} - \frac{R_1}{R_3}$$

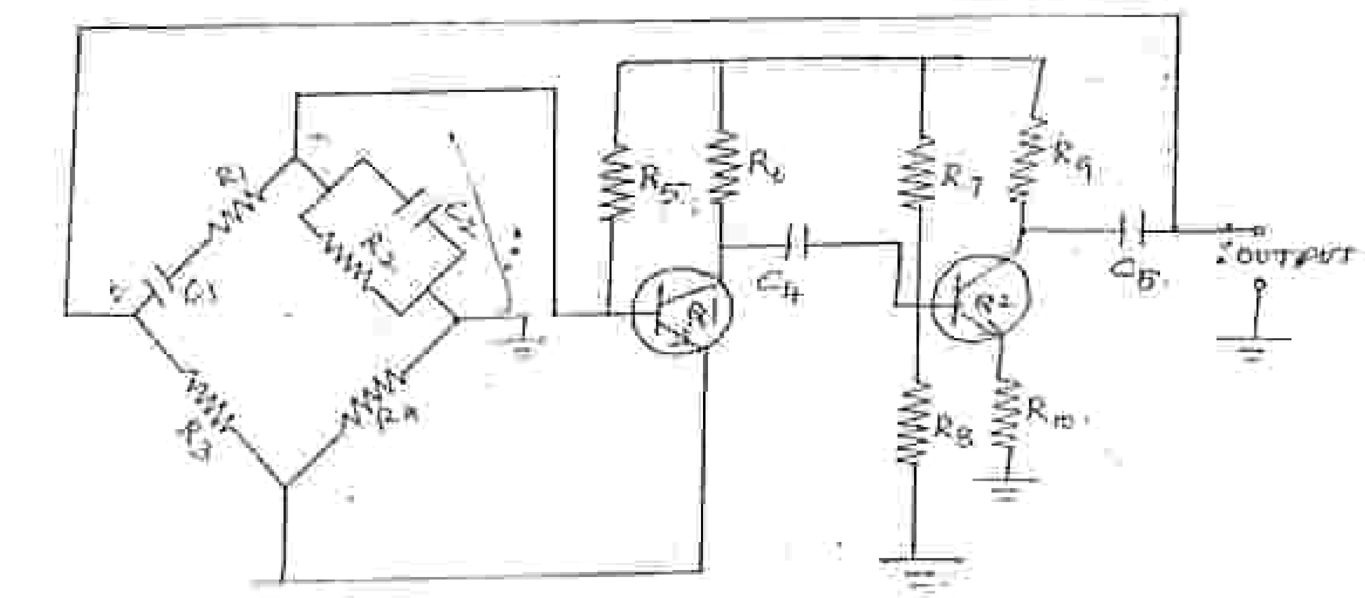
$$\frac{C}{C} = \frac{R_2}{R_4} - \frac{R}{R} \Rightarrow \frac{R_2}{R_4} = 2.$$

Hence, $$f = \frac{1}{2\pi\sqrt{R \cdot R \cdot C \cdot C}}$$

$$\boxed{f = \frac{1}{2\pi RC}}$$

which is the general eqn. for the frequency of the bridge circuit.

<u>WIENS BRIDGE OSCILLATOR CIRCUIT :-</u>



* This oscillator is also a phase-shift oscillator. It has two transistors, each producing a phase shift of 180°, and thus producing a total phase shift of 360° or 0°.
* It is a two stage amplifier with an R-C bridge circuit.
* By adding wien bridge feedback network, the oscillator becomes sensitive to a signal of only one particular frequency.
* This is the frequency at which the wien bridge is balanced and the phase shift is 0°.
* For all other frequencies, the bridge is at off-balance i.e the voltage feedback and output voltage do not have the correct phase relationship for sustained oscillations.

BASIC PRINCIPLE OF SIGNAL DISPLAY :-

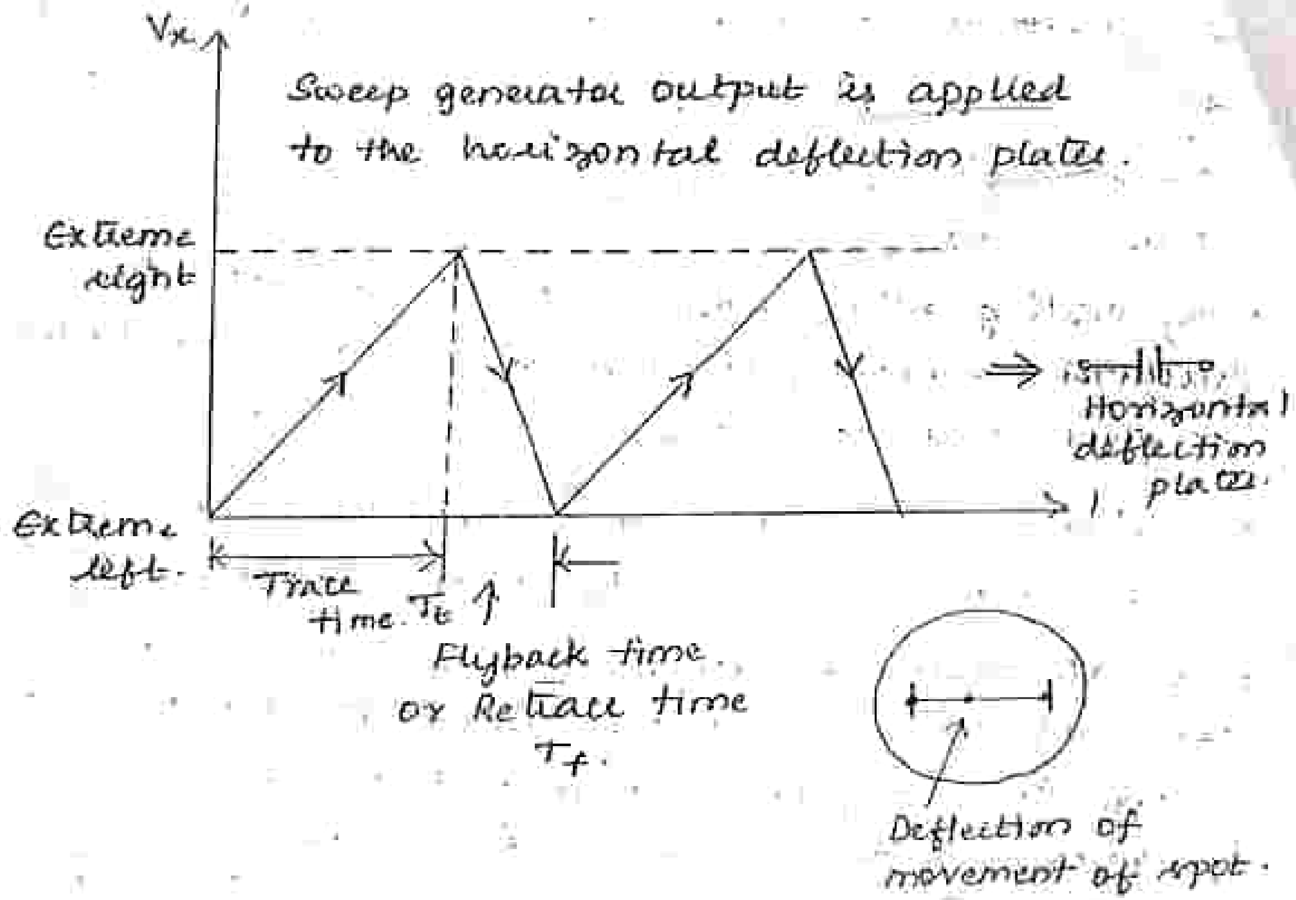
In many applications, it is required to display the voltage as a function of time.

By applying a voltage to the Y input, the vertical deflection of the electron beam will be proportional to the magnitude of this voltage.

It is then necessary to convert the horizontal deflection into a time axis.

A special unit inside the oscilloscope called the sweep generator or time base generator provides a periodic voltage waveform that varies linearly with time.

* Since this waveform resembles the teeth of hacksaw, it is also called <u>sawtooth waveform</u>.



* Assume that no voltage is applied to vertical deflecting plates, but only this sawtooth voltage V_x is applied to the horizontal deflecting plates.

* During the trace time T_t, the voltage V_x is linearly increasing with time and hence the electron beam will move linearly in the horizontal direction.

* At the end of Trace period T_t, the beam reaches extreme right hand position in the horizontal direction.

* At this instant, the voltage suddenly drops to zero in a short interval of time, known as <u>flyback time T_f</u>.

* Hence the beam suddenly jumps back to the original position at the extreme left hand side. (15)

* Then again it starts moving to the right during the next cycle of the sawtooth waveform.

* The flyback of the beam is blanked out by a suitable voltage and is not visible on the screen.

* Depending on the speed of the bright spot and the observer's vision, the trace produced by the spot will look like a horizontal straight line.

* Thus the horizontal axis is now converted into a time axis.

* When a periodically varying voltage say sinusoidal voltage is applied to the y-terminal of the scope and internally generated sawtooth voltage is applied to the horizontal deflection plates, the sawtooth voltage keeps on shifting the spot horizontally while the applied voltage shifts the spot vertically, proportional to the magnitude.

* Hence finally due to the effect of both the voltage, a familiar sinusoidal waveform can be observed in the screen.

* When the sweep frequency = signal frequency, a single cycle appears on the screen.

* When the sweep frequency < signal frequency, several cycles appear on the screen. The no.

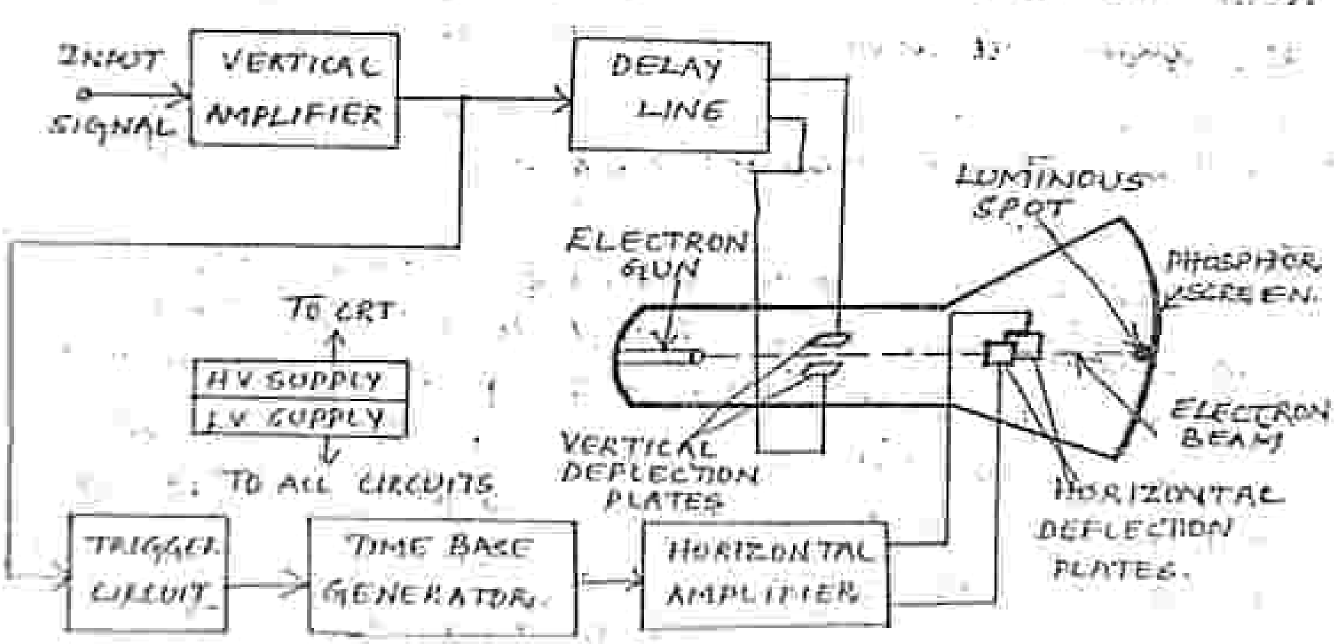
* of cycles depends on the ratio of the two frequencies.

* When the sweep frequency > signal frequency, less than one cycle appear.

* The display of spot on the screen appear stationary only when the two frequencies are same. Hence for the trace to appear stationary, the sawtooth voltage is synchronised with the signal applied to the vertical input.

CRO:-

BLOCK DIAGRAM:-



* The instrument employs a cathode ray tube. This is the heart of the oscilloscope.
* It generates the electron beam,
  accelerates the beam to high velocity,
  deflects the beam to create the image and
  contains a phosphor screen where the electron beam eventually becomes visible.
* For accomplishing these tasks, various electrical signals and voltages are required, which are provided by the power supply circuit of the oscilloscope

* Low voltage supply is required for the heater of the electron gun for generation of electron beam. (17)

* High voltage is required of the order of few thousand volts which is required for cathode ray tube to accelerate the beam.

* Normal voltage is required for other control circuits of the oscilloscope.

* Horizontal and vertical deflection plates are fitted between electron gun and screen to deflect the beam according to input signal.

* Electron beam strikes the screen and creates a visible spot.

* This spot is deflected on the screen in horizontal direction with constant time dependent rate. This is accomplished by a time base circuit provided in the oscilloscope.

* The signal to be viewed is supplied to the vertical deflection plates through the vertical amplifier, which raises the potential of the input signal to a level that will provide usable deflection of the electron beam.

* Now electron beam deflects in two directions,

  horizontal on X-axis.

  vertical on Y-axis

* A triggering circuit is provided for synchronizing two types of deflections so that horizontal deflection starts at the same point of the input vertical signal each time it sweeps.

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VERTICAL DEFLECTION SYSTEM :-

* The function of vertical deflection system is to provide an amplified signal of the proper level to drive the vertical deflection plates without introducing any distortion into the system.

* The input sensitivity of many CROs = few millivolts per division.

* Voltage required for deflecting the electron beam = 100V to 500V peak to peak depending on the accelerating voltage and the construction of the tube.

* Hence the vertical amplifier is required to provide the desired gain from millivolt input to several hundred volt output.

* This vertical amplifier should not distort the input waveform and should have good response for the entire band of frequencies to be measured.

* The deflection plates of CRO act as plates of a capacitor.

* When the input signal frequency exceeds over 1MHz, the current required for charging and discharging of the capacitor (formed by the deflection plates) increases.

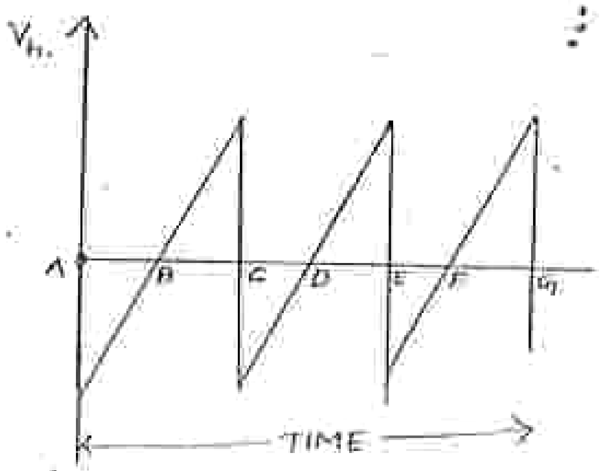
* This current should be supplied by the vertical amplifier to charge and discharge the deflection plate capacitor.

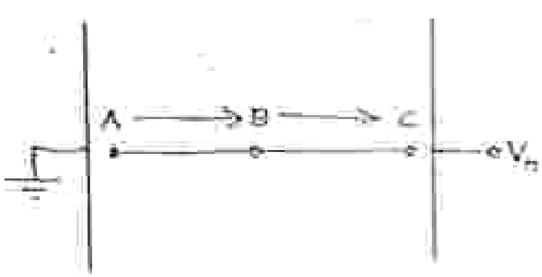
* In CRO, output signal voltage is fed to the vertical plates of the CRT + some portion of it is used for triggering the time base generator circuit.

* The output of the time base generator circuit ∴ supplied to the horizontal deflection plates through horizontal amplifier.
* The whole process which includes generating and shaping of a trigger pulse and starting of a time-base generator and then its amplification, takes time of the order of 100 ns or so.
* So the input signal of the vertical deflection plates of a CRT is to be delayed by at least 100ns or more time to allow the operator to see the leading edge of the signal waveform under study on the screen.
* For this purpose, delay line circuit is introduced between vertical amplifier and the plates of CRT.

HORIZONTAL DEFLECTION SYSTEM:-

* It is similar to the vertical amplifier.
* It increases the amplitude of the input signal to the level required by the horizontal deflecting plates of CRT.
* Assume that we supply an ideal saw-tooth signal voltage to the horizontal deflecting plates, keeping vertical deflection plates at zero potential.





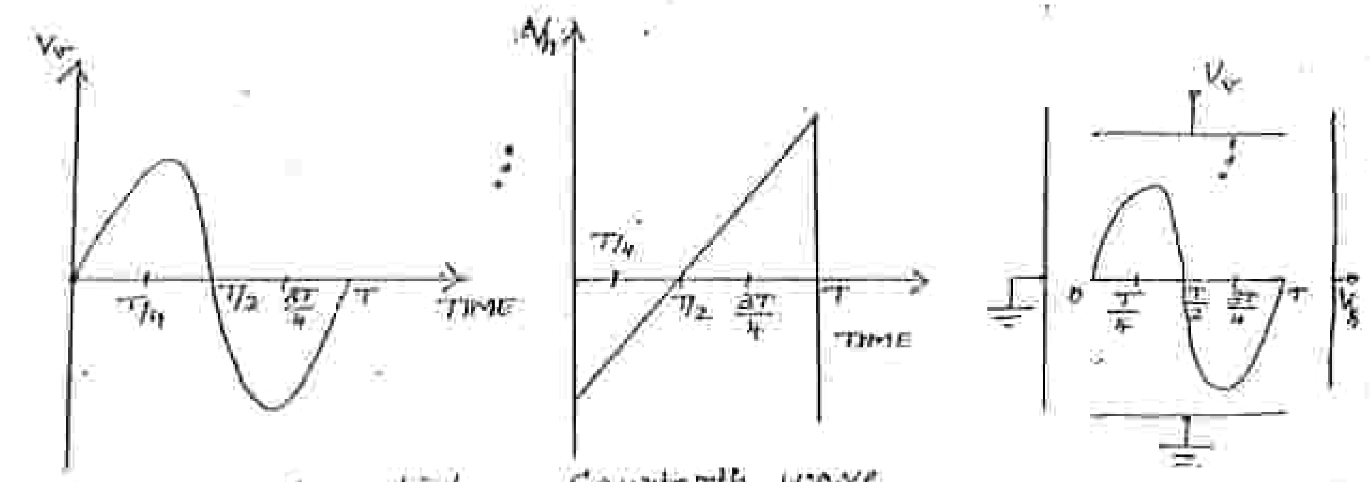
* At the starting point A in time, signal voltage is maximum but negative so the spot on the screen of CRO is at the extreme left position.
* Further at point B in time, signal voltage applied to the horizontal plates is 0 so the spot is at the centre of the screen.
* Now when voltage increases in the +ve direction and becomes maximum just before the point C, the spot on the screen is at the extreme right.
* Just after point C, next cycle of sawtooth voltage signal starts and again voltage becomes maximum negative so the spot goes back to the extreme left position of the screen from right position in no time.

From the above discussion it is clear that,

i) the spot moves from left to right over the same path again for every cycle of sawtooth voltage applied to the horizontal deflecting plates, so a horizontal line appears on the screen of CRO.

ii) The spot moves from left to right on the screen with uniform speed.

Example :-



Voltage signal applied to vertical deflection plates

Sawtooth wave voltage signal applied to horizontal deflection plates.

Pattern of signal on screen of CRO

In order to get a stationary pattern the following (31) conditions should be satisfied.

i) Both horizontal & vertical signals must start at the same instant.

ii) Ratio of frequency of horizontal and vertical signals should be a rational or fractional number.

BASIC SWEEP GENERATOR :-

* It is an electronic test generator that produces a periodic sawtooth waveform intended to modify the output of a second signal generator, which is usually a radio frequency generator.
* A sweep generator output may be used for controlling the frequency output of a signal generator to produce a sweep frequency output
* In general, a sweep generator allows a testing set-up to almost simultaneously measure the response of devices within a span of frequencies or frequency range.
* Sweep generators are used for testing the frequency response over a range of frequencies.
* Whenever RF circuits or electrical circuits have a specific frequency response, sweep generators can produce the test signal that will cover the specific frequency range.

* The basic sine wave or sinusoidal wave is a periodically time-changing voltage that cycles smoothly from zero to positive peak, then into zero, then negative peak and back into zero. (22)

* A complete cycle will have two zero points and two peak points, which are positive & negative.

* A sweep generator creates an electrical waveform with a linearly varying frequency and a constant amplitude.

* These are commonly used to test the frequency response of electronic filter circuits.

* These circuits are mostly transistor circuits with inductors & capacitors to create linear characteristics.

* Time base generators do not ordinarily provide sweep voltages that are exactly linear, although we desire a linear rise of voltage.

* A linear sweep may get distorted in the course of transmission.

Hence the deviations are,

Slope or sweep speed error e_s.

$$e_s = \frac{\text{Difference in slope at the beginning and end of slope}}{\text{Initial value of slope}}$$

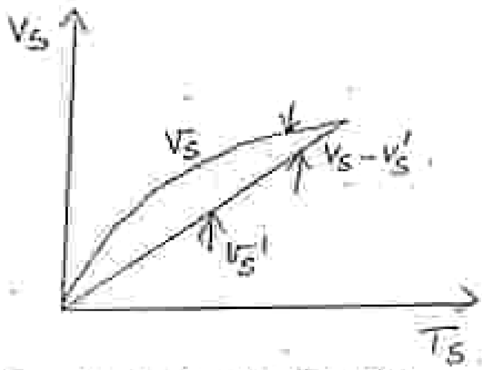
Displacement error

$$e_d = \frac{(V_s - V_s')_{max}}{V_s}$$

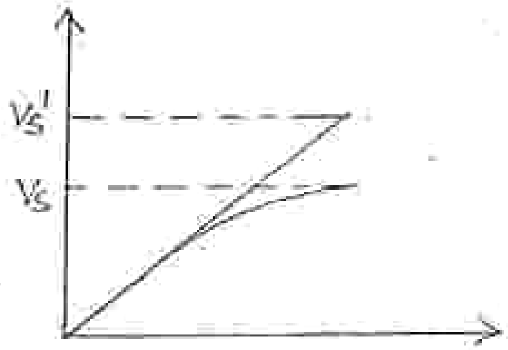
$$e_d = \frac{\text{Difference between actual sweep voltage and linear sweep voltage}}{\text{maximum value attained by sweep.}}$$

Transmission error

$$e_t = \frac{\text{Difference between maximum amplitude of i/p and o/p}}{\text{maximum amplitude of signals.}}$$



Displacement error.



Transmission error.

X-Y MODE AND LISSAJOUS PATTERNS :-

Consider a voltage waveform V_y as a function of another waveform V_x, with same frequency. When the parameter time (t) is to be eliminated for both signals, X-Y mode operation is used.

In X-Y mode, one signal is applied to the vertical deflecting plates, whereas the other to the horizontal deflecting plates.

The X-Y button on the front panel of the oscilloscope disconnects the triggering signal from the horizontal deflection system and connects the second signal instead.

* Thus in X-Y mode, the graph is plotted between two applied signals.

* The patterns formed by graphs so formed are called <u>Lissajous patterns.</u>

* It is stationary on the screen of CRO.

* It means that the spot, traces out the same pattern for every cycle of a voltage signal.

* To have a steady pattern on the CRO, the ratio of frequencies of vertical and horizontal voltage signals should be a rational or fractional number.

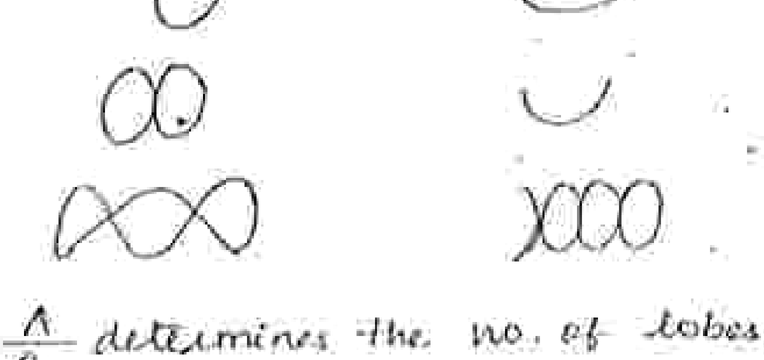
* So the condition for Lissajous pattern is,

$$\frac{f_y}{f_x} = \frac{A}{B}$$ A, B are integers and ratio of frequencies.

* Lissajous patterns are of 2 types.

i) closed Lissajous pattern.

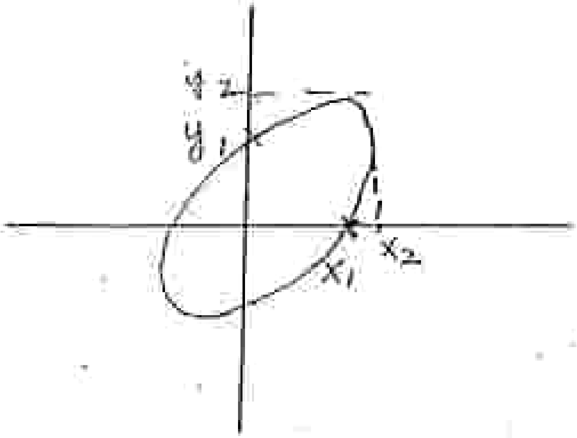
ii) Open Lissajous pattern.



$\frac{A}{B}$ determines the no. of lobes in the pattern.

If a and b is the amplitude of the both (25).
the waveforms, then

$\frac{a}{b}$ determines the relative width-to-height ratio of the curve.



Phase angle $\theta = \sin^{-1}\left(\frac{x_1}{x_2}\right)$.

APPLICATIONS OF CRO:-

* Voltage measurement.
* Current measurement.
* Examination of waveform.
* Measurement of phase and frequency.

DUAL TRACE OSCILLOSCOPE:-

* The comparison of two or more voltages is very much necessary in the analysis and study of many electronic circuits.

* This is possible by using more than one oscilloscope but in such a case it is difficult to trigger the sweep of each oscilloscope precisely at the same time.

* A common and less costly method to solve this problem is to use dual trace oscilloscope or multitrace oscilloscopes.

* In this method, the same electron beam is used to generate two traces which can be deflected from two independent vertical sources.

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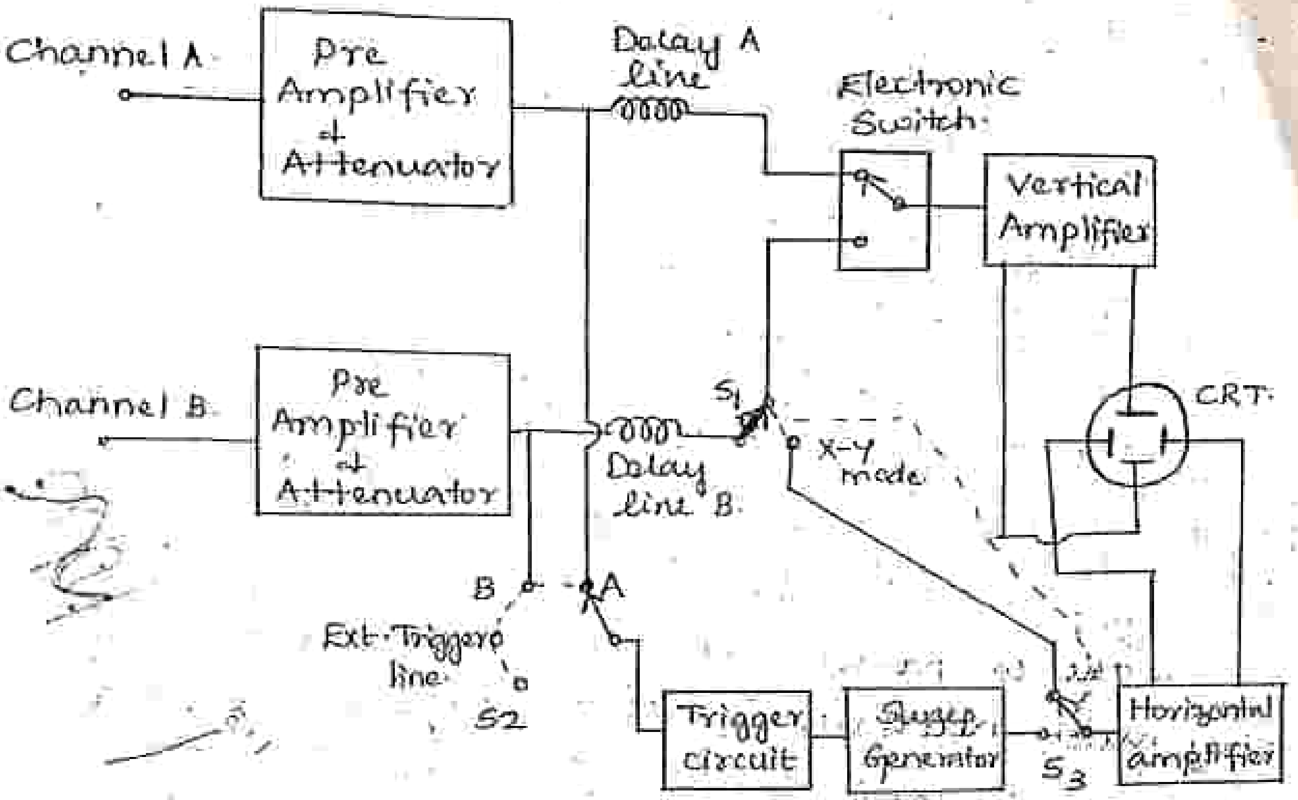

* There are two seperate vertical i/p channels, A and B.

* A seperate pre amplifier and attenuator stage exists for each channel.

* Hence amplitude of each input can be individually controlled.

* After pre amplifier stage, both the signals are fed to an electronic switch.

* The switch has an ability to pass one channel at a time via delay line to the vertical amplifier.

* The time base circuit uses a trigger selector switch S2 which allows the circuit to be triggered on either A or B channel, on line frequency or an external signal.

* The horizontal amplifier is fed from the sweep generator or the B channel via switch S3.
* The X-Y mode means, the oscilloscope operates from channel A as the vertical signal and the channel B as the horizontal signal.
* Thus in this mode very accurate X-Y measurements can be done.

DIGITAL STORAGE OSCILLOSCOPE:-

Disadvantages of analog storage oscilloscope:-

* There is a definite duration of time that it can preserve a stored waveform. eventually the waveform is lost.
* The power to the storage tube must be ON, as long as the image is to be stored.
* The trace of the storage tube is usually not as fine as that of a normal CRT.
* The writing rate of the storage tube is less, which limits the speed of the analog storage oscilloscope.
* It is considerably more expensive than a conventional CRT.
* Needs additional power supply.
* Only one image can be stored. For comparing two traces they are to be superimposed on the same screen & displayed together.

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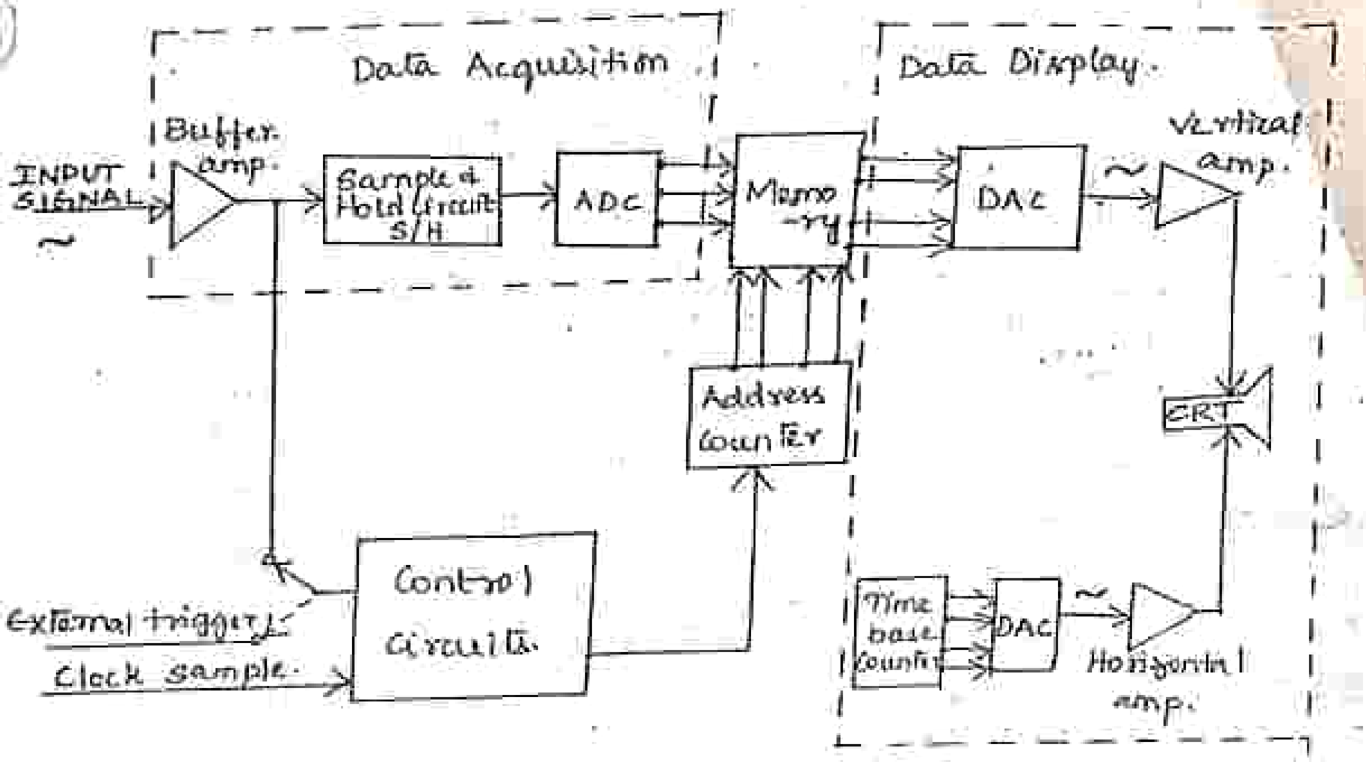

* It uses both DAC and ADC for digitizing, storing and displaying analog wave forms.

* The overall operation is controlled and synchronised by the control circuits. The control circuit usually has a microprocessor executing a control program stored in ROM.

* The data acquisition portion of the system contains a sample and hold and an ADC. It repetitively samples and digitizes the i/p signal at a rate determined by the sample clock. It then transmits the digitized data to memory for storage.

* The control circuits make sure that successive data points are stored in successive memory locations by continually updating the memory's ADDRESS COUNTER.

* When memory is full, the next data point from the ADC is stored in the first memory location, writing over the old data and this continuous for successive data.

This data acquisition and the storage process continues until the control circuits receive a trigger signal from either the i/p waveform or an external trigger source.

* When the triggering occurs, the system stops acquiring data further and enters the display mode of operation, in which all or part of the memory data is repetitively displayed on the cathode ray tube.

* In display operation, two DACs are employed for providing the vertical and horizontal deflection voltages for the cathode ray tube.

* Data from memory produce the vertical deflection of the electron beam.

* The time base counter provides the horizontal deflection in the form of a staircase sweep signal.

* The control circuits synchronise the display operation by incrementing the memory ADDRESS COUNTER and the time-base counter at the same time so that each horizontal step of the electron beam is accompanied by a new data value from the memory to the vertical DAC.

* The counters are continuously recycled so that the stored data points are repetitively replotted on the screen of the CRT.

* The screen display consists of discrete data representing the various data points but the number of dots is usually so large that they tend to blend together and appear to be a smooth continuous waveform

* The display operation is terminated when operator presses a front-panel button that commands the digital storage oscilloscope to begin a new data acquisition cycle.

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MODULE - 6.

TRANSDUCERS.

Definition :-

An electronic instrumentation system consists of a no. of components to perform a measurement and record the results. A generalised measurement system consists of 3 major components.

1) an i/p device.
2) a signal conditioning or processing device.
3) an o/p device.

An i/p device receives the quantity to be measured and delivers a proportional or analogous electrical signal to the signal conditioning device. Here the signal is amplified, attenuated, filtered, modulated or converted into a form which is acceptable by the o/p signal.

The i/p quantity for most instrumentation system is a non-electrical quantity. In order to use electrical methods and techniques for measurement, manipulation and control, the non-electrical quantity is generally converted into an electrical form by a device called a transducer.

Hence a transducer is a device which when actuated transforms energy from one form to another. In other words, it converts quantity to be measured to a usable electrical signal.

Transducers contains two parts that are closely related to each other.

i) the sensing element.

ii) the transducing element.

* A sensor is used to just detect a parameter in one form, from the i/p device and report it in another form to the o/p device.

* The transducing element actually does the conversion, converts the sensor o/p to suitable electrical form.

CLASSIFICATION OF TRANSDUCERS :-

5mark

The transducers can be classified,

1) on the basis of transduction form used.

2) primary and secondary transducers.

3) passive and active transducers.

4) analog and digital transducers.

5) transducers and inverse transducers.

i) On the basis of transduction form used.

- Capacitive transduction
- Electro magnetic Transduction.
- Inductive Transduction.
- Piezoelectric transduction.
- Photovoltaic transduction.
- Photo conductive transduct

Capacitive Transduction:-

* The quantity to be measured is converted to a change in capacitance.

Electromagnetic Transduction:-

* The quantity to be measured is converted to voltage which is induced in the conductor by change in magnetic flux.
* Works on the principle of Faraday's law of induction.

Inductive Transduction:-

* The quantity to be measured is converted into change in the self inductance or mutual inductance by changes in the magnetic in ac excited coil circuit.
* This is achieved by displacing the core of the coil that is attached to a mechanical sensing element.

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Piezo-electric Transducer :-

* The quantity to be measured is converted into a change in electrostatic charge q or voltage V.

* This change is generated by crystals when the stress is applied to them.

Photo voltaic Transducer :-

* The quantity to be measured is converted into a voltage which is generated when a junction between the dissimilar material is illuminated.

Photo conductive Transducer :-

* The quantity to be measured is converte into a change in resistance of semiconductor material by the change in light incident on the material.

2) Primary and Secondary Transducers :-

* Some transducers contain the mechanical as well as electrical device.

* The mechanical device converts the physical quantity to be measured into a mechanical signal.

* Such mechanical devices are called as the primary transducers, because they deal with the physical quantity to be measured.

* The electrical device then converts this mechanical signal into a corresponding electrical signal. Such electrical devices are called as secondary transducers.

3) Passive and Active Transducers :-

Active Transducer :-

* These transducer do not need any external source of power for their operation. Therefore they are also called as self generating type transducers.

* As the o/p of active transducers we get an equivalent electrical o/p signal.

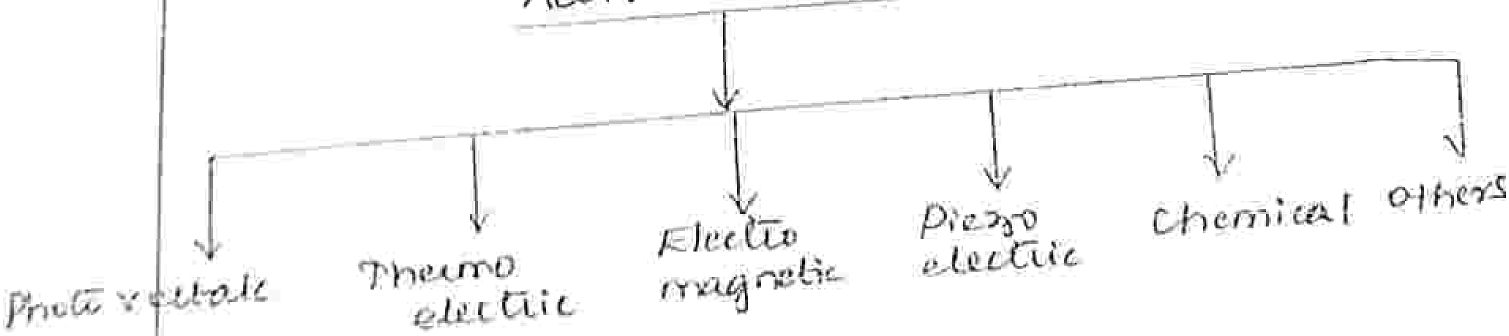
Passive Transducer :-

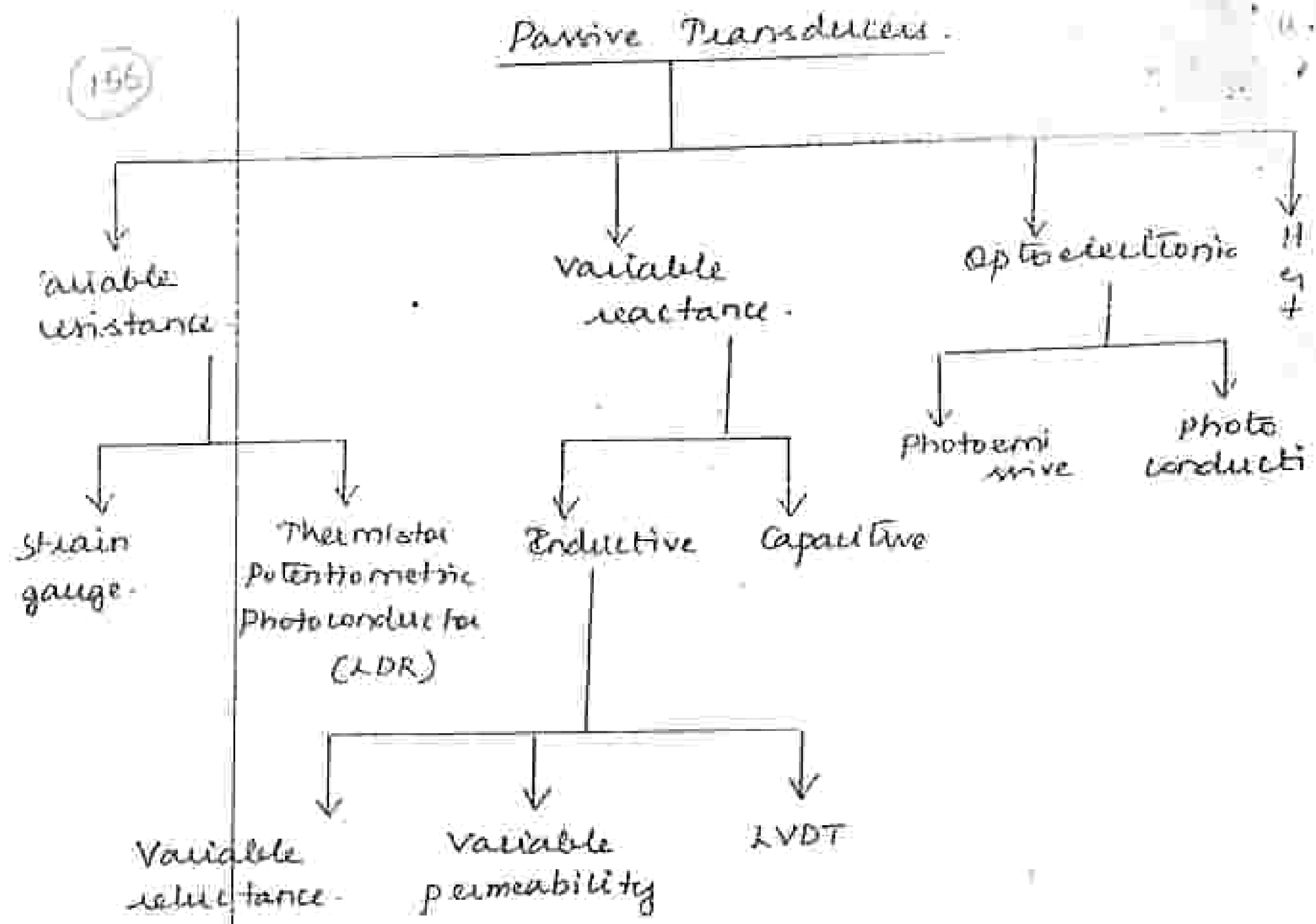
* These transducers need external source of power for their operation. So they are not self generating type transducers.

* A DC power supply or an audio frequency generator is used as an external power source

* These transducers produce the o/p signal in the form of variation in resistance, capacitance, inductance, reactance, etc.

Active Transducer.





i) Analog and Digital Transducers :-

The analog transducer convert the i/p quantity into an analog o/p which is a continuous function of time.

Eg :- strain gauge, thermocouple, transistor, etc

The digital transducers convert the i/p quantity into an electrical o/p which is in the form of pulses.

) Transducers & Inverse Transducers :-

It converts a non-electrical quantity to electrical quantity.

The inverse transducer converts electrical quantity to a non-electrical quantity.

COMMON TRANSDUCERS :-

MEASUREMENT OF DISPLACEMENT :-

The transducers which are used for measuring linear displacements are:

1) Resistive potentiometer.
2) Strain gauges.
3) Variable inductance transducers
4) LVDT
5) Capacitive transducers.
6) Piezo electric transducers.
7) Hall effect transducers.
8) Digital transducers.

The transducers required for measurement of rotary displacement are,

i) Resistive potentiometer
ii) Variable inductance transducers.
iii) RVDT
iv) Variable reluctance transducers.

LVDT

Electromagnetic and ultrasonic flow meter

Piezo electric force transducer

load cell

Strain gauge - bridge configuration for four strain gauge

RTD

Thermistor

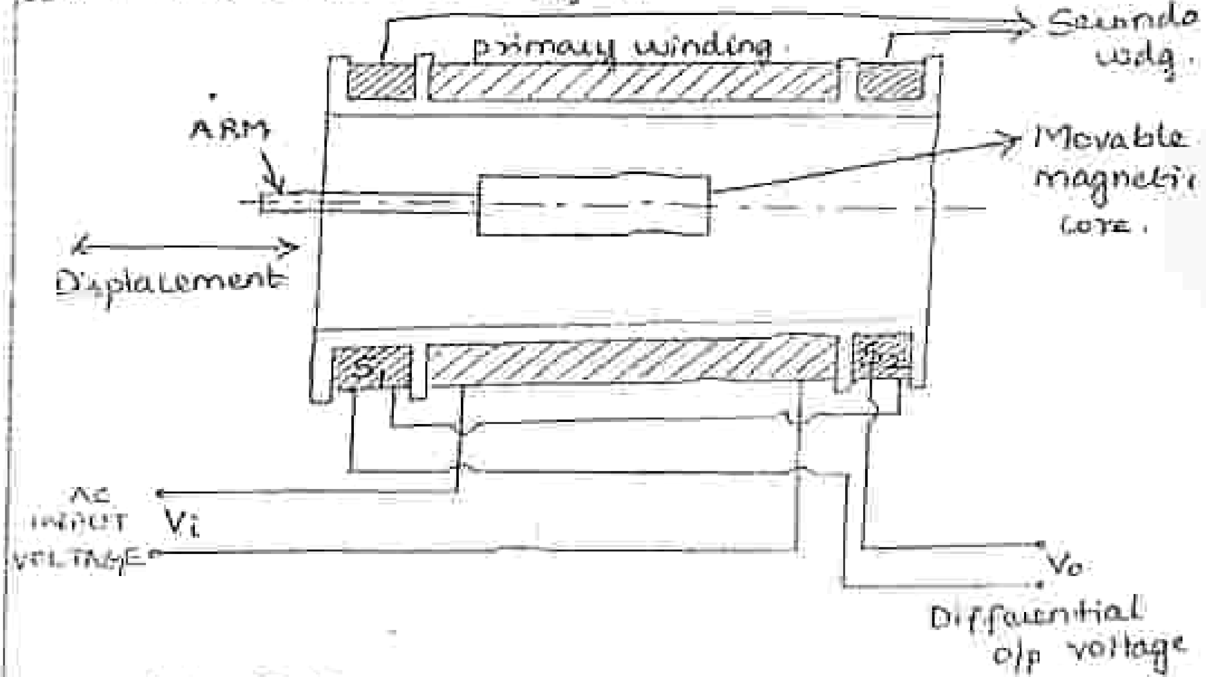
Thermocouple

(154)

Inductive transducer

LVDT :- Linear variable differential transducer

This is the most widely used inductive transducer for translating the linear motion into an electrical signal.



CONSTRUCTION :-

– It is a differential transformer consisting of one primary winding P and two identical secondary windings S_1 and S_2 wound over an insulating material.

– The secondary windings S_1 and S_2 have equal number of turns and are arranged on either side of the primary winding.

– A soft iron core, attached to the sensing element moves in the hollow portion.

– The displacement is measured by the sensing element.

- The primary winding is connected to an ac source of voltage varying from 5 to 25V and of frequency ranging from 50Hz to 20 KHz.

- When the core is moved inside the hollow portion, it varies coupling of primary winding to secondary windings S_1 and S_2.

- In null position of the core, i.e. in the central position, coupling of primary winding to both of the secondary windings are equal and so output voltages induced in secondary windings S_1 and S_2 are equal

- As the core is moved towards the left from its null position, the magnetic linkages to secondary winding S_1 increase and to secondary winding S_2 decreases.

- Therefore o/p voltage induced in S_1 increases whereas the o/p voltage induced in S_2 decreases.

- The movement of the core to the right will have opposite effect.

- S_1 and S_2 are connected in series opposition so that difference of o/p voltages of secondary windings gives the measurement of displacement

– With the movement of the core in one direction away from the null position, the differential voltage increases and it is in phase with the i/p voltage of the primary winding.

– When the movement of the core is in the other direction from the null position, it causes the differential o/p voltage to increase but 180° out of phase with the primary winding.

– Now by measuring the magnitude and comparing the phase of differential o/p voltage with the input primary voltage, amount and direction of displacement of core can be found

– LVDTs normally range for displacement varies from ±0.01 mm to ± 25 mm.

RVDT :- (Rotary Variable Differential Transformer)

– It is a device for measuring angular displacement and operates on the same principle as LVDT.

– A cardioid-shaped cam of a magnetic material is used as the core.

– The input shaft fastened to the core is mounted at the centre of the coil former on which the primary and secondary windings are wound symmetrically.

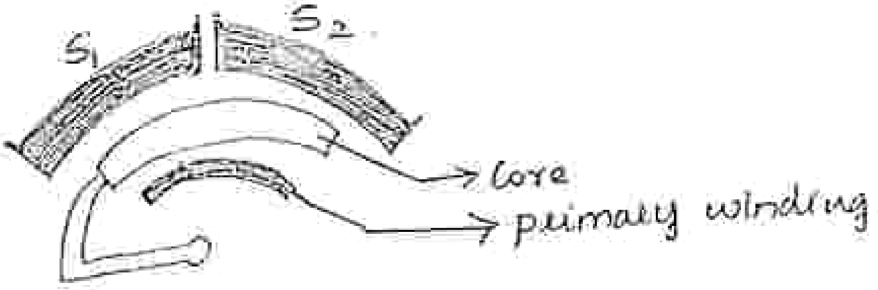
- The cardioid shape core is so chosen as to give linear output over a specified angle of rotation.

- In null position of the core, ie in central position, o/p voltages induced in secondary windings S_1 and S_2 are equal and in opposition, therefore the differential o/p is zero.

- Angular displacement of the rotor from the null position gives differential voltage o/p which is proportional to the angular displacement.

- clockwise rotation of the core produces increasing differential output voltage of one phase while counter-clockwise rotation produces increasing differential o/p voltage of opposite phase.

- So by measuring the magnitude and comparing the phase of differential o/p voltage with the i/p primary voltage the amount of angular displacement and its direction may be determined.



PROBLEMS :-

1) An LVDT produces an rms output voltage of 2.6V for displacement of 0.4 μm. Calculate the sensitivity of LVDT.

$$\text{Sensitivity} = \frac{\text{RMS value of o/p voltage}}{\text{Displacement in } \mu m}$$

$$= \frac{2.6}{0.4} = 6.5 \text{ V}/\mu m.$$

STRAIN :-

STRAIN GAUGE :-

The strain gauge is a passive resistive transducer which is based on the principle of conversion of mechanical displacement into resistance change.

Strain is defined as the change (ΔL) in length L per unit length.

$$\text{Strain} = \frac{\Delta L}{L} \; (\mu \text{ strains}).$$

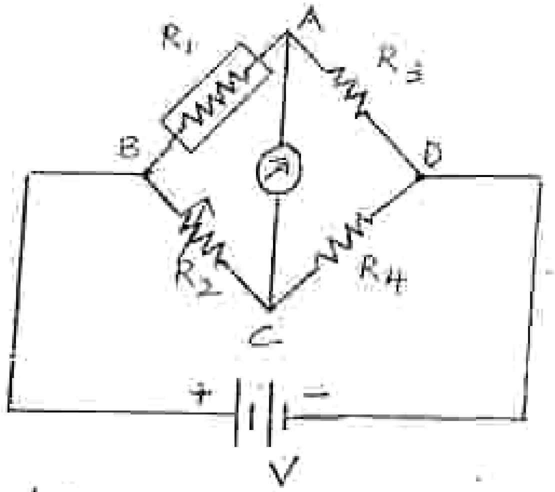
Since the magnitude of strain is small, it is practically difficult to measure directly. Hence a gauge which can measure strain directly is used. Such a gauge is called as strain gauge.

Basic principle of Strain Gauge :-

The resistance of the wire in an electrical strain gauge changes as a function of strain. The change in resistance is measured using a wheatstone bridge.

A Wheatstone bridge is a circuit designed for accurate measurement of small variations in resistance. In Wheatstone bridge, used for measurement of variation in resistance of strain gauge, one arm consists of the strain gauge while the other three arms have standard resistances of nearly equal resistance.

- The Wheatstone bridge can be used in two ways. 1) Null method. 2) Deflection method.



Null Method :-

- One of the other three resistances is readjusted, manually or automatically to balance the bridge and the required adjustment gives a measure of change in strain gauge resistance.

- Let the initial resistance of the strain gauge under normal condition be R_1. All the other resistances are taken equal to the strain gauge resistance R_1.

- when some strain is applied, the variation occurs. Let the variation in the resistance of strain gauge be ΔR_1.

Gauge factor = unit change in resistance per unit change in length

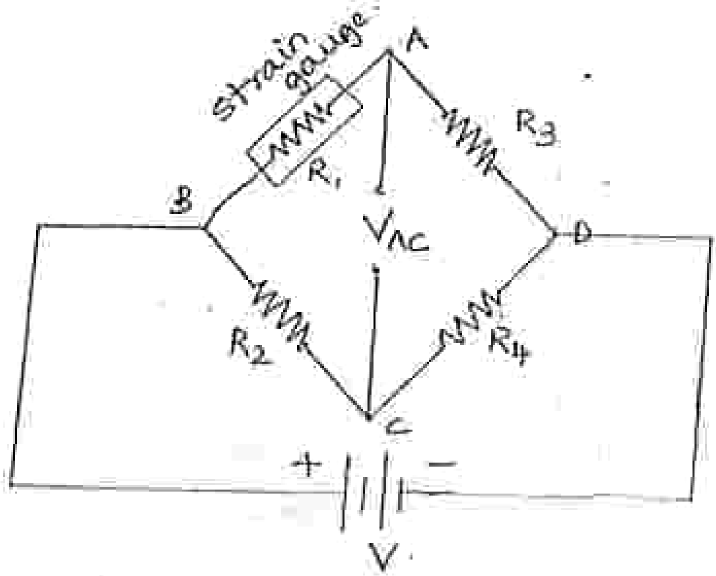
$$G = \frac{\Delta R_1/R_1}{\Delta L/L}$$

$$\therefore G = \frac{\Delta R_1/R_1}{\Delta L/L} = \frac{\Delta R_1/R_1}{\text{strain}}$$

$$\text{strain} = \frac{\Delta R_1/R_1}{G}$$

ΔR_2 gives the measurement of strain directly.

Deflection Method :-



Under balanced condition,

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

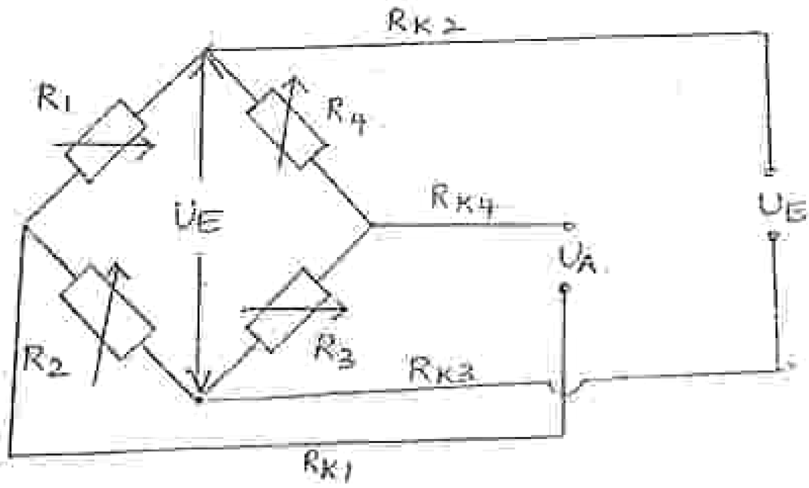
- When the bridge is balanced, the o/p voltage that appears across the terminals C and A is zero.

- Now the change in resistance of the strain gauge unbalances the bridge and a voltage appears across the terminals A and C.

- This unbalance causes the deflection in the meter.

- This deflection indicates the variation in strain gauge resistance.

<u>Bridge Configuration for four Strain Gauges:-</u>



In a full bridge circuit, active strain gauges are used in all four bridge arms R_1 to R_4.

U_E → excitation signal.
U_A → o/p signal.

The value of the o/p voltage depends on the ratio of resistors. $\frac{R_1}{R_2}$ & $\frac{R_4}{R_3}$.

In case of balanced bridge,

$R_1 = R_2 = R_3 = R_4$.

or $\frac{R_1}{R_2} = \frac{R_4}{R_3}$.

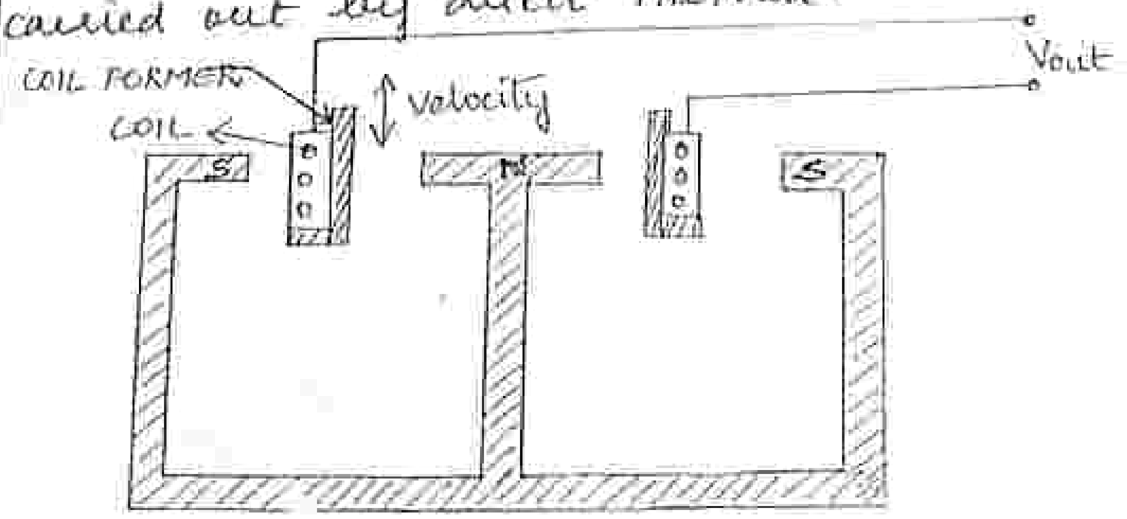
STRAIN is the amount of deformation of a body due to an applied force

VELOCITY :-

Linear Velocity :- Electromagnetic transducer principle

This linear velocity is measured by converting linear motion into an angular motion when distance travelled is long.

In case, if the distance travelled is small, linear velocity measurement is carried out by direct method.



- An emf is induced in the coil when the flux linking with the coil changes.

- The magnitude of this induced emf is given by,

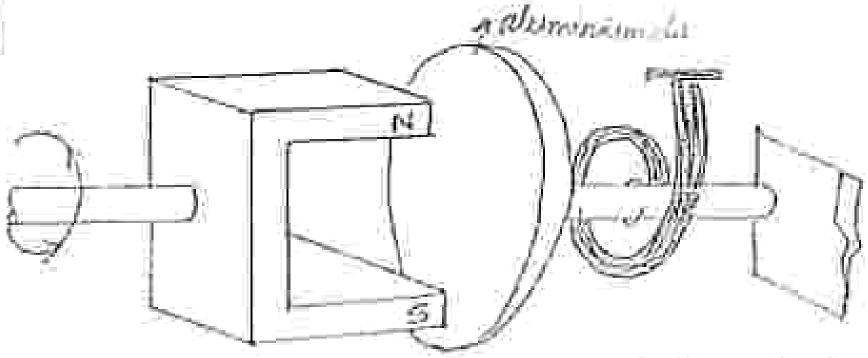
$$e = B l v \sin\theta \text{ volts.}$$

$B \rightarrow$ flux density of the magnetic field in Tesla.
$l \rightarrow$ length of the moving coil in m.
$v \rightarrow$ relative velocity of the coil & magnet in m/s
$\theta \rightarrow$ angle of coil movement with the direction of magnetic field.

Angular Velocity :-

In many cases the only way for measuring linear velocity is by its conversion into an angular velocity.

1) Eddy Current Tachometer :-



- Consists of a permanent magnet NS coupled mechanically with the test shaft and an aluminium disc facing the poles of the permanent magnet.

– Rotation of the permanent magnet induces voltages in the disc and also produces circulating eddy currents in the di[sc]

– The interaction of these eddy currents with the magnetic field of the permanent magnet produces a deflecting torque

– This disc rotates until this deflecting torque is balanced by the restoring torque of the spring.

– The angular deflection of the tachometer moving element is directly proportional to the speed of rotation being measured.

2) DC Generator Tachometer :- Electromagnetic ...

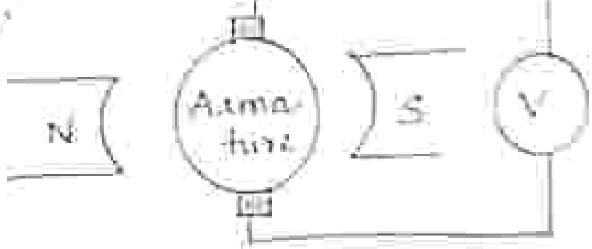
– It is an ordinary mini dc generator.

– Consists of small armature rotating in a constant magnetic field.

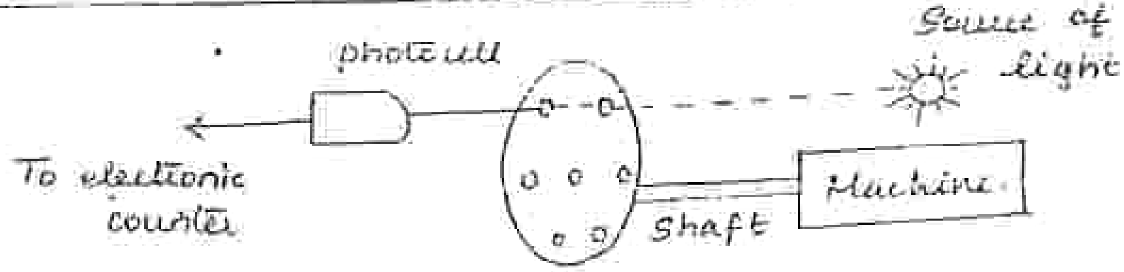
– The armature is coupled to the shaft of the machine whose speed is to be measured

– The emf generated by this transducer is proportional to the speed of rotation of armature coupled mechanically to the shaft of the test machine.

– The emf is measured with a high resistance voltmeter which may be calibrated in terms of rpm.



3) Photoelectric pickup Tachometer :- Photovoltaic transducer principle



* This consists of light source, a photocell and a rotating disc placed between the light source and the photocell.

* This disc has a number of equidistant holes on its periphery and is mechanically coupled to the shaft of the machine whose speed is to be measured.

* When the hole comes in between the light source and the photocell, the light falling upon the cell gives an output pulse.

* When the opaque portion comes, the cell does not give any output.

* Thus the photovoltaic cell is constantly turned on and off, at a frequency which depends on the no. of holes on the disc and its speed of rotation.

$\therefore f = \text{Speed in rps} \times \text{no. of holes on the disc}$

(or) $RPM = \dfrac{60f}{\text{No. of holes on disc}}$

FLOW :-

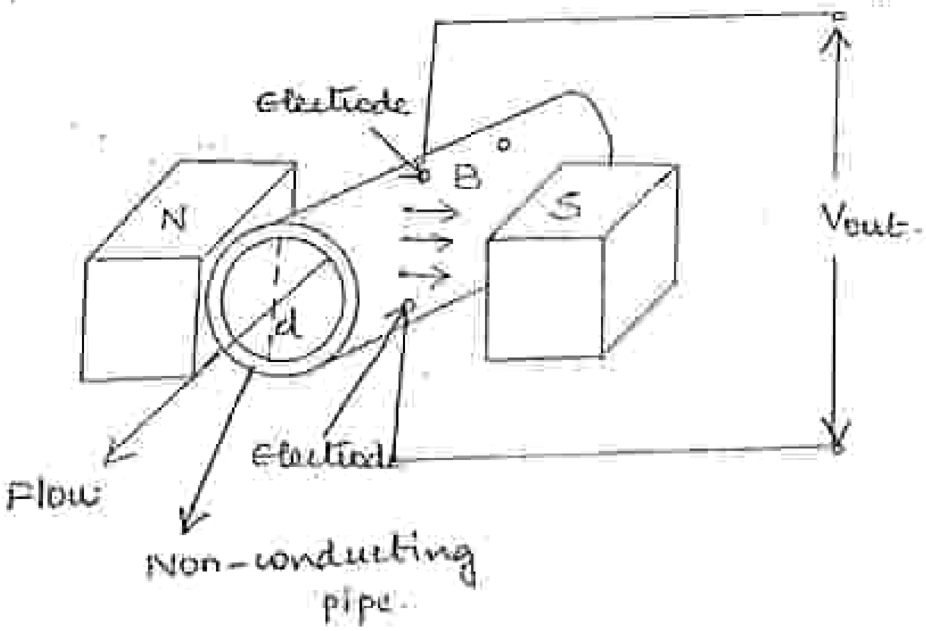
ELECTROMAGNETIC FLOW METERS :-

* Based on Faraday's law of electromagnetic induction.

* ie an emf is induced in a conductor of length l metres when it moves with a transverse velocity of v m/s across a magnetic field of strength B wb/m² and the induced emf in the conductor is given by the expression,

$$e = Blv \text{ volts.}$$

* Since the voltage induced depends on the rate at which the conductor moves through the magnetic field, the magnitude of voltage induced can be used as an indication of the flow rate of liquid.



* It consists of a non-conducting pipe with two electrodes mounted on the tube wall.
* The ends of the electrodes are in contact with the fluid flowing in the tube.

* Surrounding the tube, there is a magnet with its field at right angles to the electrodes.

* The fluid flowing through the pipe should be conductive.

* As the conductive fluid flows through the insulated tube, through the magnetic field, a voltage is induced across the electrodes.

* The voltage induced across the electrodes varies directly in proportion to,

  i) the magnetic field strength, B
  ii) the distance between electrodes, d
  iii) the average velocity of conductive fluid through the tube.

* Therefore if B and d are kept constant, the voltage induced will be directly proportiona to the flow rate of the liquid.

* The induced voltage is then amplified and connected to a suitable indicating or recording instrument.

Advantages :-

1) It does not obstruct the flow in any way that may cause pressure drops
2) No moving parts. Hence no friction.
3) Insensitive to viscosity, density & flow disturbances.
4) Good accuracy and reliability.

5) Simple and rugged in construction.

6) Response is fast.

Disadvantages :-

1) The output signal is usually very small, in the order of microvolts.

2) Hence requires large amplification.

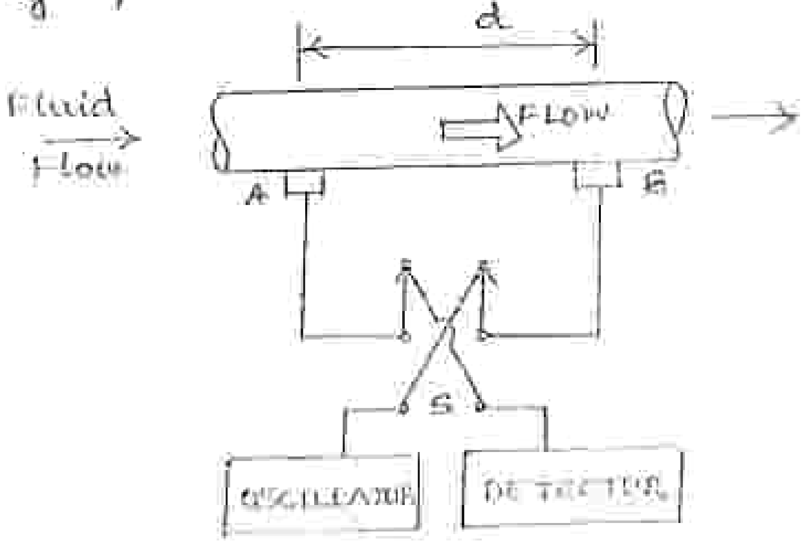
3) The device tends to be expensive, especially for smaller pipe sizes.

ULTRASONIC FLOWMETER :-

* Also called as acoustic flowmeter.

* There are two types based on the principle they operate.

1)



* This flowmeter works on the principle called the "Doppler effect".

* Two piezocrystals A and B working both as transmitter and receiver of ultrasonic signals alternately are mounted on the pipe.

* Therefore the ultrasonic signals are transmitte between them as well as through the liquid.

* An oscillator supplies alternately A or B through the switch S when the detector is connected simultaneously to B or A respectively.

* The detector is a phase sensitive device which measures the transit time from upstream to downstream and vice versa.

* If $C \rightarrow$ velocity of sound propagation in medium in m/s,

  $v \rightarrow$ linear velocity of fluid flow in m/s,

  $d \rightarrow$ distance in m between the piezocrystals A and B,

  $f \rightarrow$ frequency in Hz.

then,

The transit time in the direction of flow,

Velocity = distance / time

$$\Delta t_1 = \frac{d}{C+v} \quad \text{——— (1)}$$

$\frac{1}{T} = f$

The transit time in the opposite direction of fluid flow,

$\theta = \omega t$

$= 2\pi f t$

$= \frac{2\pi f d}{C+v}$

$$\Delta t_2 = \frac{d}{C-v} \quad \text{——— (2)}$$

phase angle in the direction of flow,

$$\Delta \phi_1 = \frac{2\pi f d}{C+v} \text{ radians.}$$

phase angle in the opposite direction.

$$\Delta\phi_2 = \frac{2\pi f d}{c-v} \text{ radians}$$

$$\therefore \Delta\phi_2 - \Delta\phi_1 = \frac{2\pi f d}{c-v} - \frac{2\pi f d}{c+v}$$

$$= 2\pi f d \left[\frac{1}{c-v} - \frac{1}{c+v}\right]$$

$$= 2\pi f d \left[\frac{c+v-c+v}{c^2-v^2}\right]$$

$$= \frac{4\pi f d v}{c^2-v^2}$$

If v is very small than c, then,

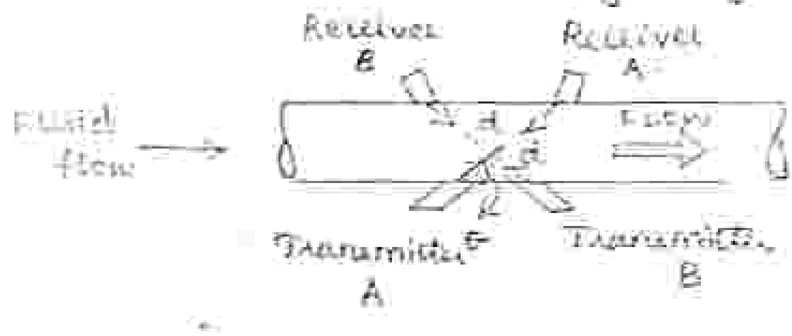
$$\Delta\phi_2 - \Delta\phi_1 = \frac{4\pi f d v}{c^2} = k v$$

Hence the difference in phase shift is proportional to the flow rate of the liquid

$$\Delta\phi_2 - \Delta\phi_1 \propto v$$

2) Transit-time flow meter:-

* Also called as leading edge meter



* Also called leading-edge meter.
* Here two sets of piezocrystals are mounted.
* Waves from the piezocrystals are sent at an angle θ with the direction of fluid flow in either way.
* The velocity of the ultrasonic signal from the transmitter A to the receiver A is increased while the signal from the transmitter B to receiver B is decreased
* If,

c → sound propagation velocity in medium, m/s

v → fluid flow velocity, m/s

d → distance between the transmitter & receiver, m.

θ → angle between the sound path and pipe axis

Then, the repetition frequencies in the upstream side and the down stream side will be,

$$f_a = \frac{c + v\cos\theta}{d}$$

$$f_b = \frac{c - v\cos\theta}{d}$$

The difference in frequency is given by,

$$\Delta f = f_a - f_b = \frac{2v\cos\theta}{d}$$

By measuring Δf, and knowing θ & d, the velocity can be

Advantages :-

1) The output is independent of C, therefore the effects of pressure and temperature are avoided

2) measurement is insensitive to viscosity, pressure and temperature variations

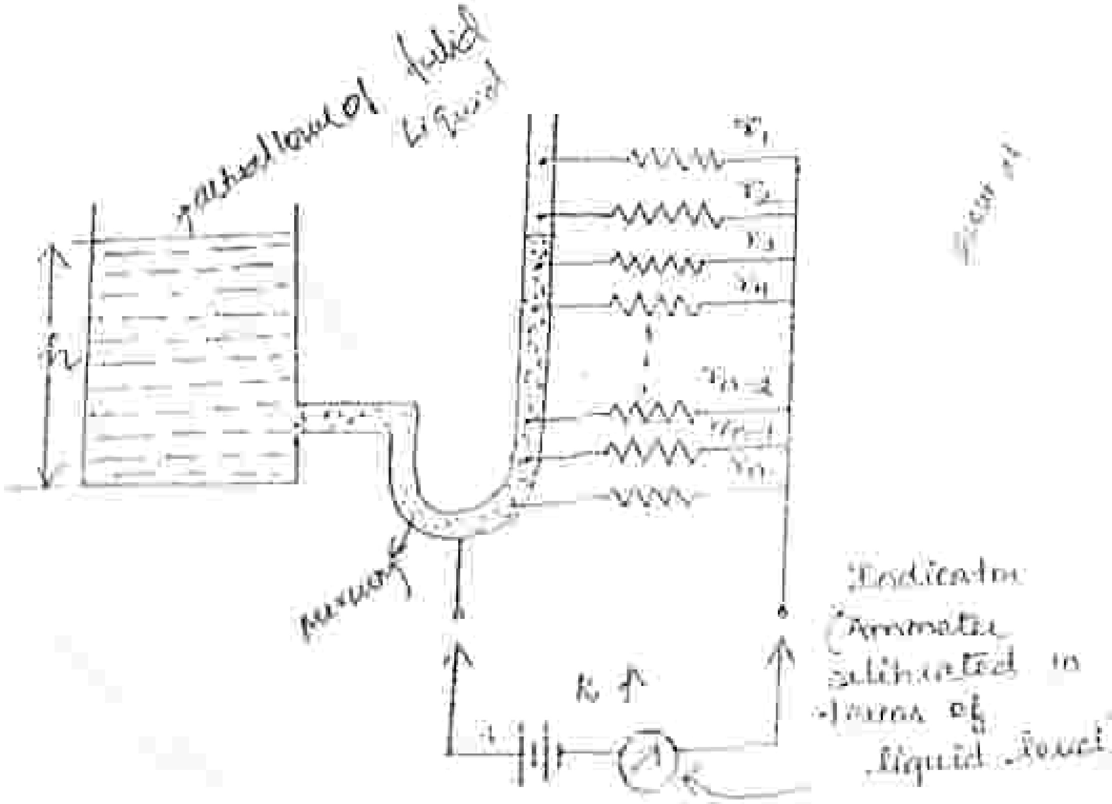
3) No obstructions to flow, bidirectional measuring capabilities, good accuracy, fast response, wide frequency range & can be employ for any pipe size.

LIQUID LEVEL :-

1) Resistive Method :-

* Simplest electrical method of measuring liquid level.

* Also known as contact point type



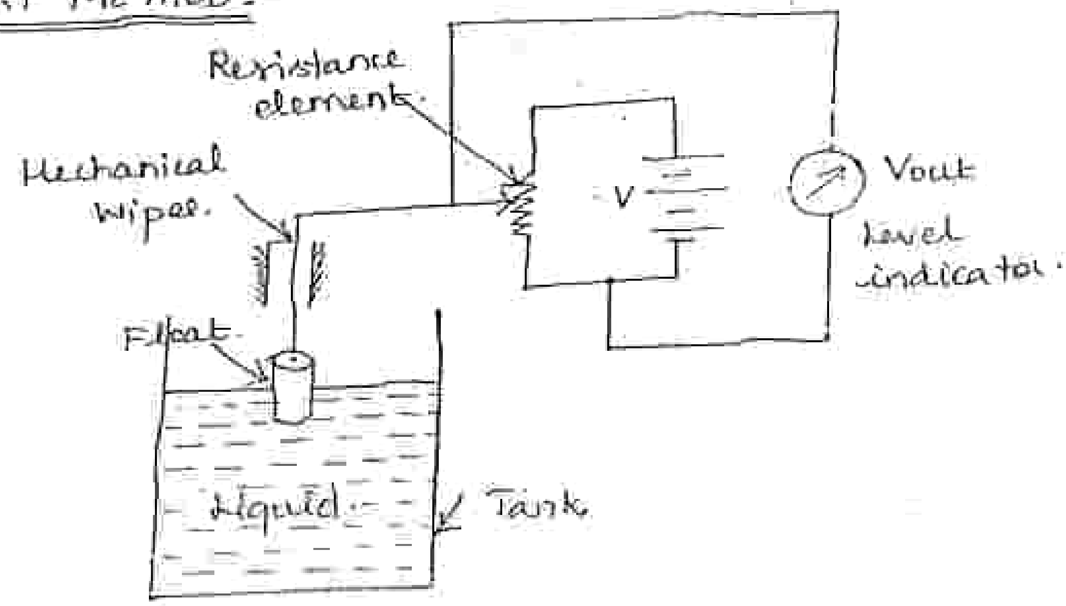
* A no. of resistances of suitable values are placed at various levels of liquid.

* As the liquid level rises, the mercury level also rises and shorts the successive resistances and so the resistance R decreases or current through indicator increases.

* Resistances $r_1, r_2, \cdots r_n$ are so chosen that $1/R$ is a linear function of the liquid level.

* In this method of level measurement we get step-wise record of the level.

FLOAT METHOD :-



* The float is the primary sensing element.
* Operates on the basis of buoyancy effect.
* The float is mechanically coupled to some suitable displacement transducer, such as potentiometer or LVDT, for continuous indication & recording.

(178)

Velocity = displacement / time

* In the fig, a resistance potentiometer is used.

* The output voltage is proportional to the liquid level h and the o/p terminals of the potential divider can be taken to remote location for display and control

ULTRASONIC METHOD :-

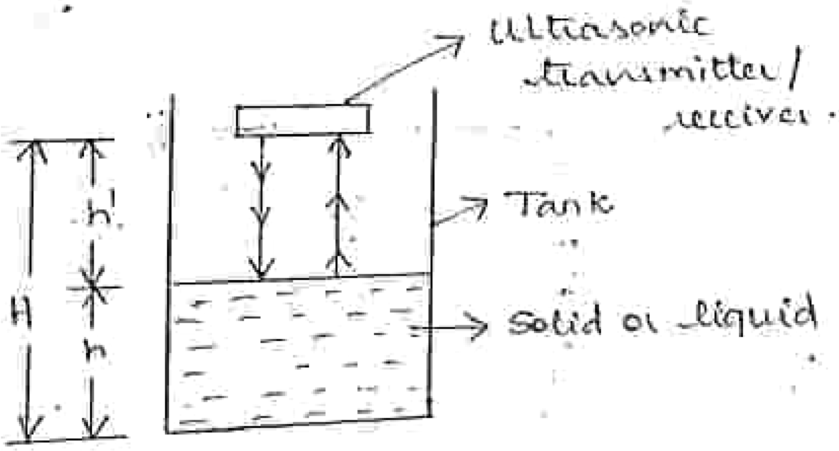
- It can be used for measurement of level of either solids or liquids.

- An ultrasonic transmitter - receiver may be mounted at the top of the tank projecting a beam downward.

- This beam is reflected back by the surface of the fluid contained in the tank and received by the receiver.

- The time interval, t between the instants of transmitting beam and receiving the reflecting beam is a measure of distance travelled by the beam.

- Since total distance between the ultrasonic set and the bottom of the tank, H is fixed so the time interval, t is a measure of fluid level h.

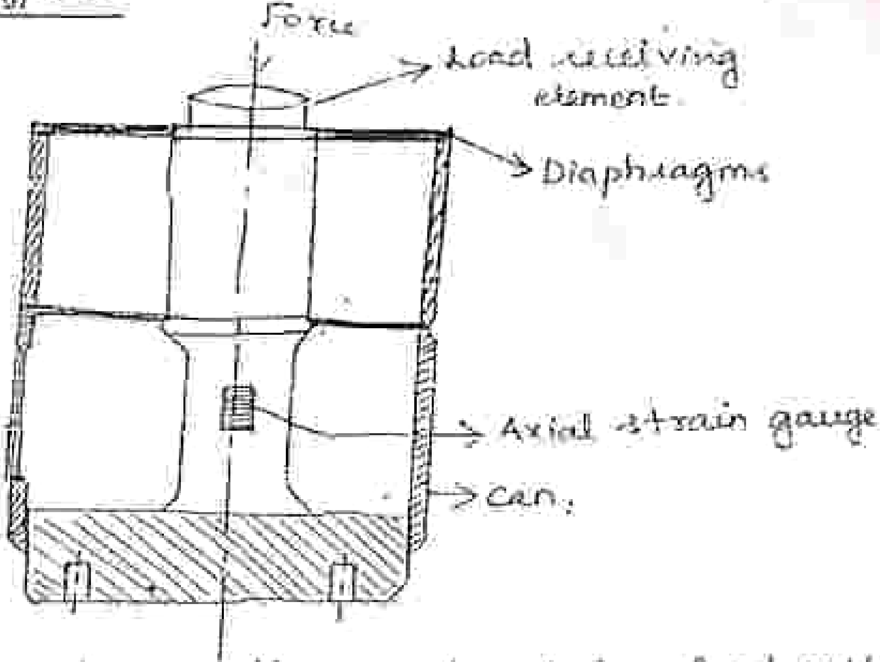


FORCE :-

LOAD CELL :-

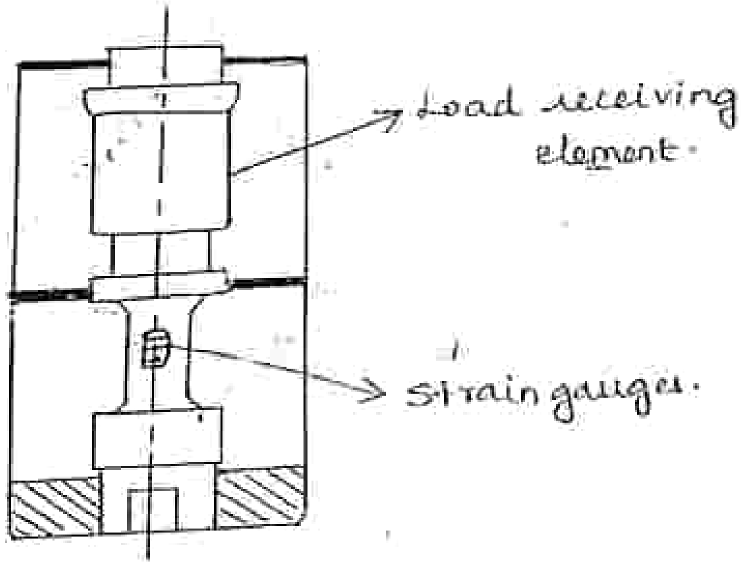
- A load cell is an electromechanical device that converts weight or force into an electrical signal.
- widely used for measurement of static and dynamic forces.
- The heart of the load cell is the load receiving element to which the strain gauge bridge network is bonded.
- This device can be designed for handling a wide range of operating forces with high level of reliability and thus it is one of the most popular transducers used in industrial measurements.

i) Column type :-



* This design is usually employed in load cells of capacity of 2250 kg or more.
* Two strain gauges called the active gauges are bonded axially and two additional gauges called the Poisson gauges are mounted 90° to the axially positioned strain gauges.
* The bottom section of the load cell is welded on the base structure.
* A diaphragm is welded to the top of this lower can.
* The diaphragm is welded both to the edge of the can and center column.
* The upper can is then welded to the connection between the diaphragm and the lower can, thereby completing the basic outshell or can of the load cell.

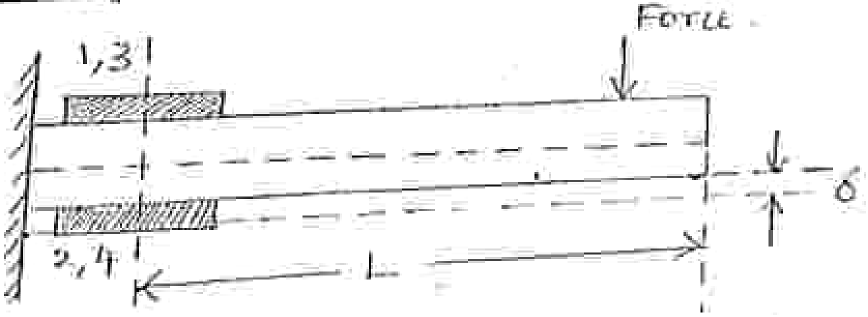
2) Universal load cell :-



* The load receiving element is at both ends for the attachment of loading hardware.

* Such a cell is called universal or bidirectional load cell.

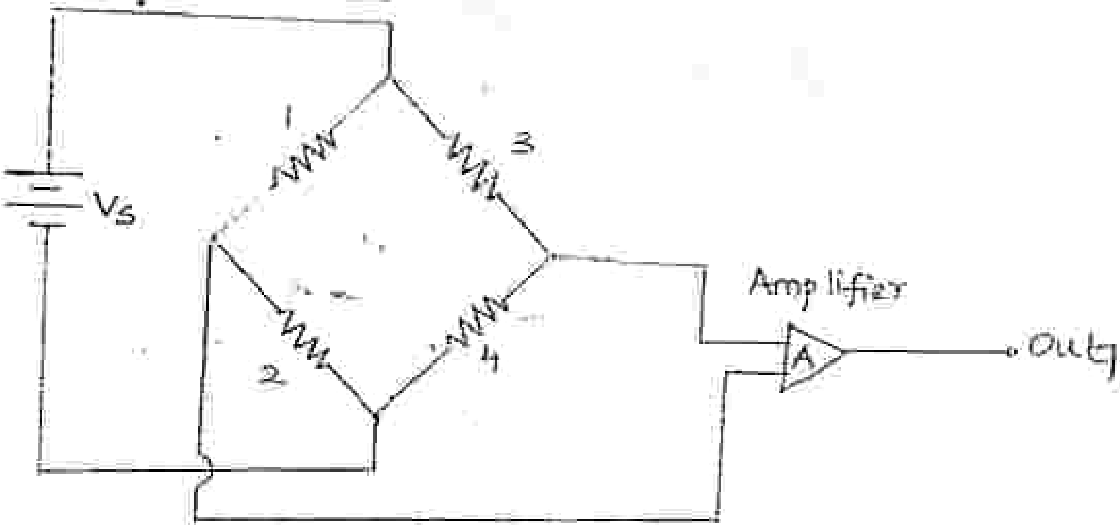
2) Bending beams :-



* A load cell consists of a load beam on which several strain gauges are mounted or bonded.
* When a force is applied to the free end of this beam, the strain gauges bonded to the element undergoes a resistive change.
* This resistive change is proportional to the ... load applied.

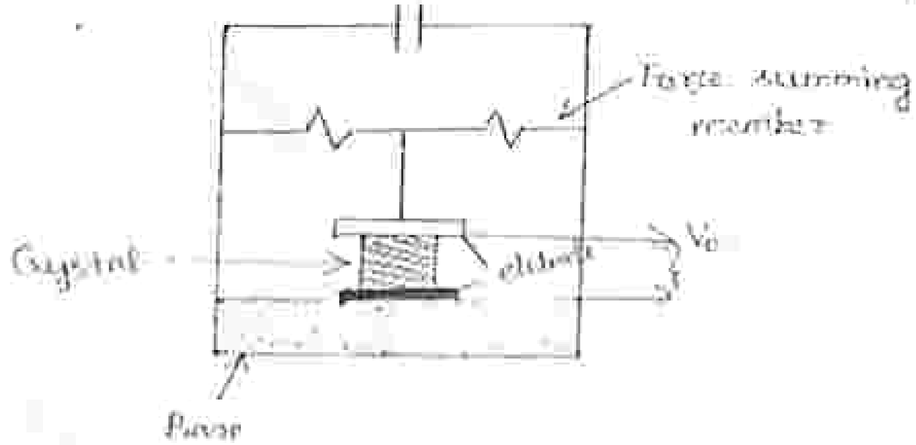
* In this type, two gauges experience tension and two compression.

SHEAR ELEMENT :-



In this type of design of a load cell, four or eight gauges are bonded to a specifically designed element and wired to form a wheatstone bridge.

PIEZOELECTRIC FORCE TRANSDUCER :- Piezoelectric transducer



* A piezoelectric transducer may be used to measure force.

* It is an effective force measuring device which is used in many instruments for measuring force or force related quantities.

* When a mechanical force is applied on the surface of the crystal, dimensions of the crystals are changed and electric potential appears across certain surfaces of the crystal.

* In converse, if varying potential is applied to the axis of the crystal, the dimensions are changed and the crystal deforms.

* This phenomenon is called piezoelectric effect and the materials which exhibit this effect are called piezoelectric materials.

* A crystal is placed between the solid base and force summing member.

* Metal electrodes placed on to faces of piezoelectric crystal are taken out to measure output.

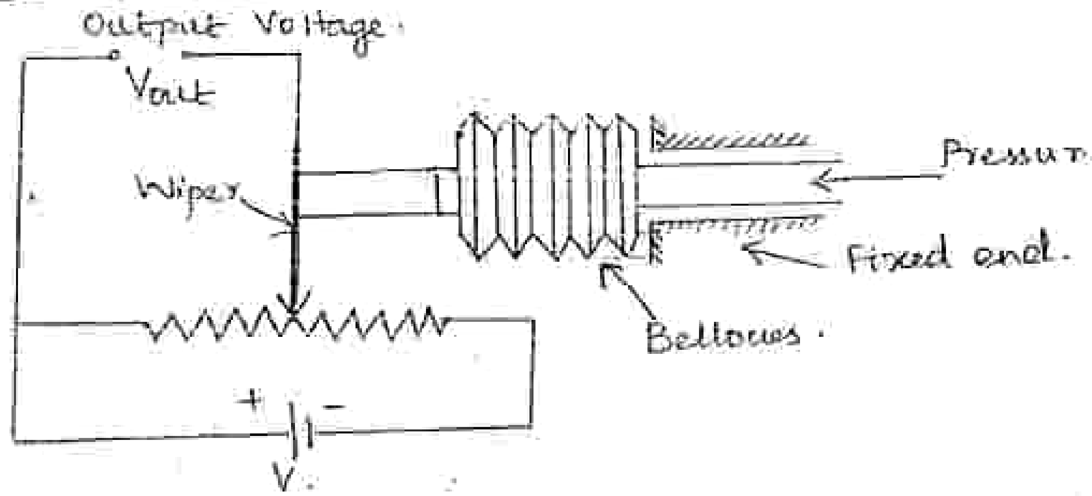
* The electrodes becomes plates of the parallel plate capacitor.

* Thus it can be considered as charge generator.

PRESSURE :-

$$\text{Pressure} = \frac{\text{Force}}{\text{Unit area}}$$

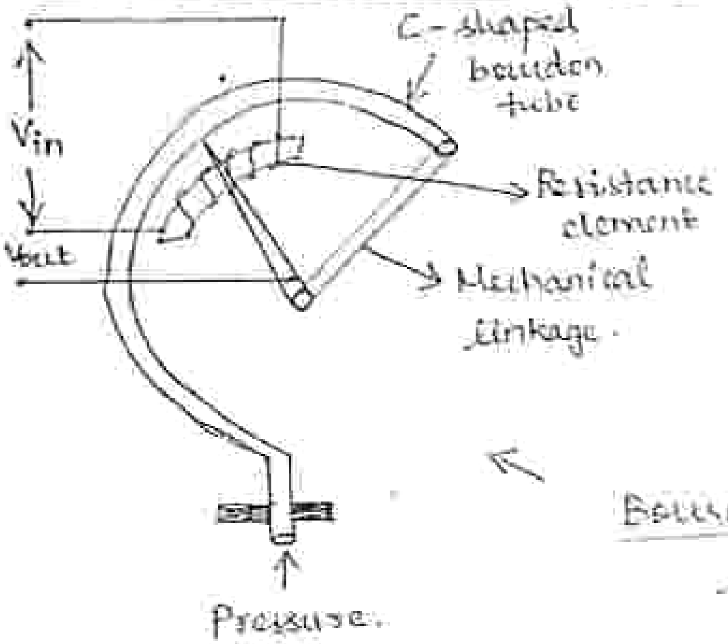
1) By using Bellows :-



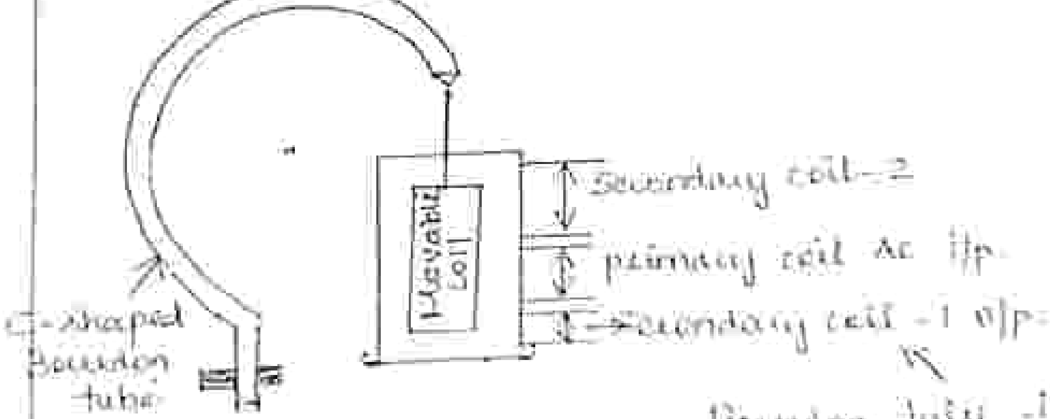
* Here bellows is the primary detector for pressure.
* Potentiometer is the secondary transducer
* One side of the bellows is fixed and pressure is applied inside the bellows which in turn expands or compresses the bellows depending upon the nature of pressure.
* A rod fitted on the other side of the bellows moves and transmits the motion to the potentiometer acting as a secondary transducer.
* This arrangement is used for measurement of low pressure.

2) Using C-shaped Bourdon tube :-

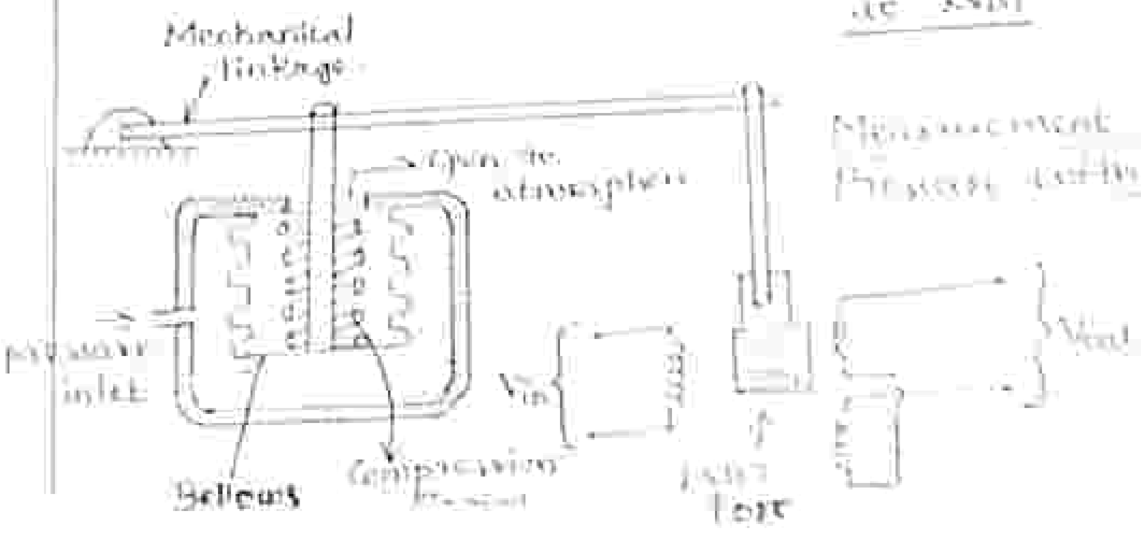
* The bourdon tube can be linked to a potentiometer or LVDT for measuring pressure.



Bourdon tube linked to potentiometer.



Bourdon tube linked to LVDT



Measurement of Pressure with LVDT

C-shaped bourdon tube and bellows can be used along with LVDT to measure pressure.

The pressure which is to be measured is applied to the outside of the bellows forcing it to contract against the push of a compressing spring

As it moves, it actuates a mechanical linkage which moves the coil of an LVDT to furnish an electrical output signal.

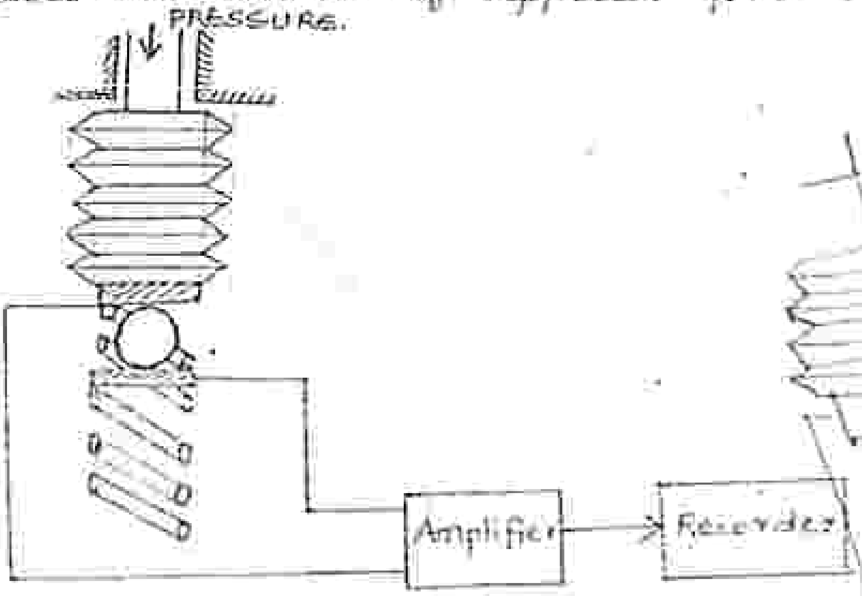
3) Using Piezoelectric Crystal :-

* Piezoelectric crystal along with bellows is used in measurement of pressure.

* When the pressure is applied to a crystal through a bellow, it causes a deformation in the structure of the crystal.

* Hence an emf is produced.

* This output emf may be measured to indicate the value of applied force or pressure.



4) Using Oscillation Transducer :-

* An oscillation transducer in combination with a force summing device can be used.

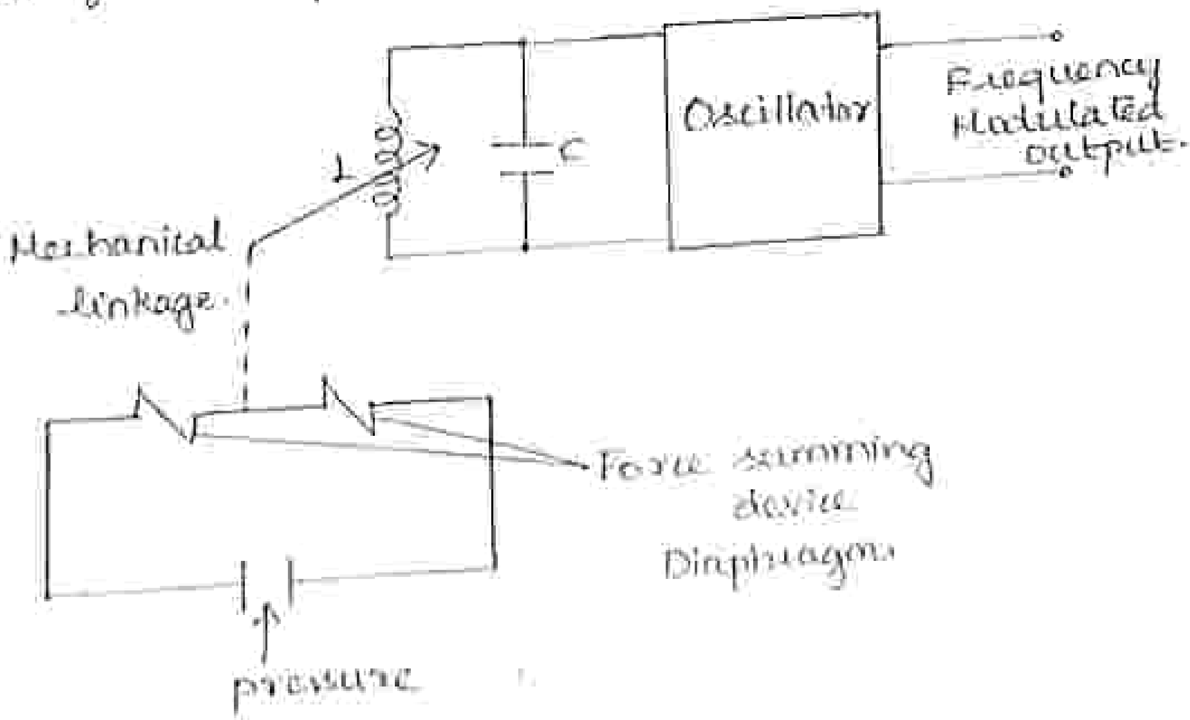
* Here the diaphragm is used as a force summing device.

* The force summing device is used for changing the inductance L or capacitance C of the tank circuit of the oscillator.

* Here L is varied.

* The output frequency of the oscillator is affected by variation in inductance L.

* The modulated output of the oscillator is demodulated and calibrated in terms of applied force or pressure.



TEMPERATURE :-

RTD :-

* Also called as resistance thermometer.
* RTD stands for Resistance Temperature Detector
* Principle :-

Almost all pure metals have the property of varying their resistances with temperature, and change in resistance is almost directly proportional to the change in temperature.

* Electrical resistance with temperature, for most metallic materials can be represented by an equation of the form,

$$R_t = R_0 \left(1 + \alpha t + \beta t^2 + \gamma t^3 + \dots \omega t^n\right).$$

$R_0 \rightarrow$ resistance at reference temp.

$R_t \Rightarrow$ resistance at temp t.

$\alpha \Rightarrow$ temp. coefficient of resistance.

$\beta, \gamma, \omega \Rightarrow$ coefficients determined on the basis of two or more known resistance temperature points

The no of terms necessary depends on the material, the desired accuracy and the range of operation. β and other higher coefficients are small, therefore can be eliminated.

$$R_t = R_0 (1 + \alpha t).$$

* RDT is applicable for measurements of small temperature differences as well as for wide ranges of temperature.

* RDT does not generate own voltage so a voltage source is required in the measuring circuit.

* Wheatstone's bridges are usually employed for measurement of variations in resistance owing to changes in temperature.

Requirements of resistance materials in RTD:-

1) High temp. coefficient of resistance in order to give change in resistance for even a small change in temperature. ie ~~sen~~ larger sensitivity.

2) High resistivity.

3) linear relation between resistance + temperature

4) Stable electrical characteristic.

5) sufficient mechanical strength.

* Platinum, Nickel + copper are most commonly used resistance materials.

* Platinum is the most suitable material for RTDs for most laboratory work and for industrial measurements of high accuracy

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Theory :-

(4C)

* The resistance of platinum increases with the increase in temperature according to the law.

$$R_t = R_0(1 + \alpha t + \beta t^2).$$

* $\alpha = 0.0037$, $\beta = 0.00000057$ for platinum

For simplicity, the equation for small temperature variations is modified as,

$$R_t = R_0(1 + kt).$$

$k \rightarrow$ fundamental constant. Its value is determined by testing a platinum resistance thermometer with melting ice (at 0°c) and boiling water (at 100°c).

CONSTRUCTION :-

* The platinum resistance thermometer usually consists of a thin platinum wire wound in the form of a free spiral, or it held by an insulated carrier such as mica or ceramic

* The diameter of the wire varies from 0.02 mm to 0.2 mm.

* The wire should be smooth, free from defects.

* The ratio of resistance at 100°c to the resistance at 0°c should be larger than 1.391.

* The platinum wire is subjected to special treatment in order to ensure constancy of resistance over prolonged use and to avoid resistance changes owing to dimensional changes

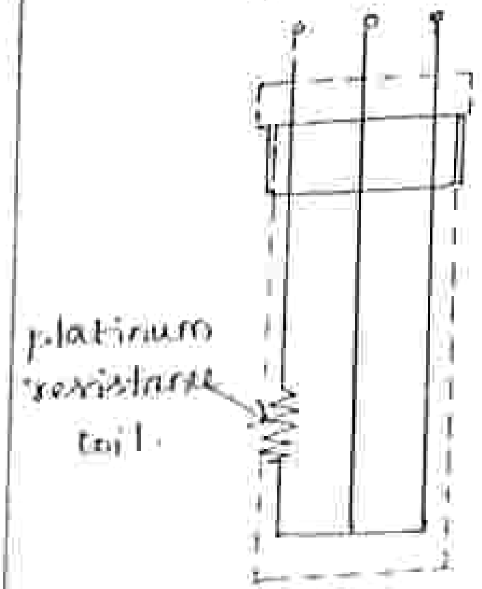
* The resistive wire is generally enclosed in a protective tube made of glass, quartz, porcelain, stainless steel or nickel for protection from mechanical damages and chemical reactions.

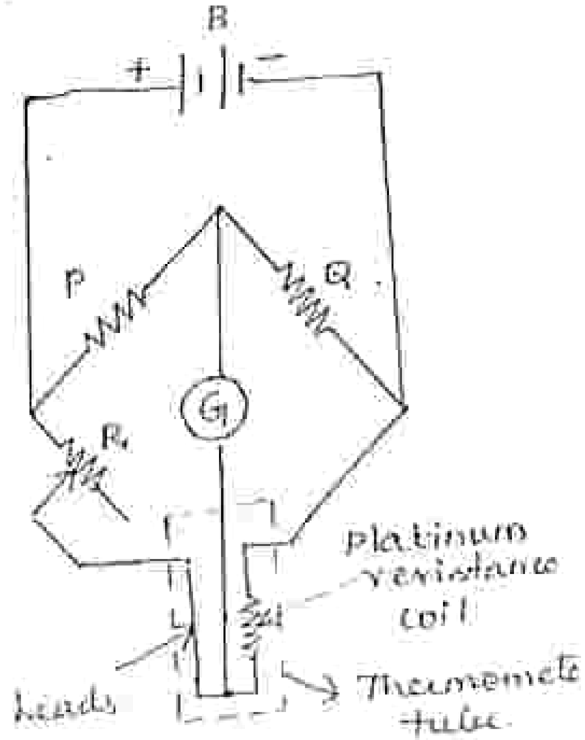
* These protective tubes may be filled with air at high pressure.

* Joints inside the thermometer tube are usually welded as metallic soldering gives off fumes at high temperatures and deteriates the platinum.

* The thermometer winding should be protected against water vapour in order to avoid corrosion and also to avoid increased leakage resistance between the windings and other joints.

* The change in resistance with change in temperature is measured by means of either a wheatstone bridge or kelvin double bridge network depending upon the accuracy required and range of measurement.





(192)

* In the figure P and Q are two ratio arms, R is the known variable resistance inserted in the third arm along with the compensating leads.

* The fourth arm is made up of a slide wire which is connected to the platinum resistance coil through connecting leads.

* The slide wire is graduated in °C and the position of the slide wire contact gives the temperature directly.

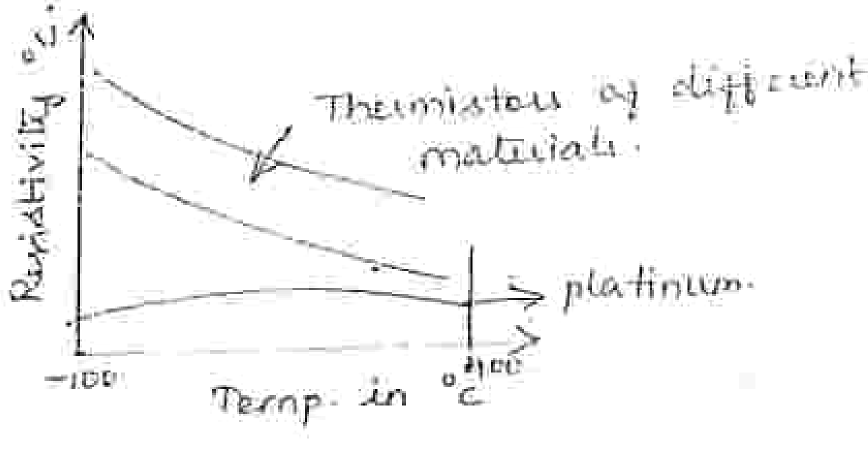
THERMISTOR :-

* Also called the thermal resistor and the name is derived from thermally sensitive resistor.

* Because the resistance of a thermistor varies as a function of temperature.

* Thermistor are essentially semiconductor devices, that behave as resistor with high negative temperature coefficient at at least 10 times as sensitive as the platinum resistan thermometer

* Negative temperature coefficient means the resistance decreases with increase in temperature



* Thermistor has a very non-linear resistance - temperature relation, from the characteristic curves. The resistance R of a thermistor at a temperature T can be given by the equation,

$$R_1 = \alpha e^{\beta/T} \quad \text{——— (1)}$$

– α & β are constants depending upon the material & manufacturing techniques.

Eqn. (1) is rewritten for temperatures T_1 and T_0 where R_1 and R_0 are resistances in ohms at absolute temperatures T_1 and T_0 resp.

$B \rightarrow$ thermistor constant.

$\beta \rightarrow$ unit $\rightarrow$ kelvin and of the order of 4000.

– The reference temperature T_0 is usually taken at 298 K or 25°C.

– Since β is constant,

$$\alpha = \frac{dR_1/R_1}{dT}$$

$$\alpha = -\frac{\beta}{T^2}$$

* Because of large change of resistance per degree of temperature variation in thermistor, they can provide good accuracy and resolution when used for measurement of temperature between –100°C and +300°C.

(194)

* If an ammeter is used for monitoring of the current through a thermistor, temperature variati as small as ± 0.1°c can be detected.

* If the thermistor is instead put into a wheatstone bridge, the measuring system can detect temperature variations as small as ± 0.001

Characteristics of Thermistors :-

The three important characteristics of thermisto are

i) Resistance - temperature characteristic
2) Voltage - current characteristic
3) Current - time characteristic.

1) Resistance - temperature characteristics :-

Thermistors behave as resistors with high negative temperature coefficient.

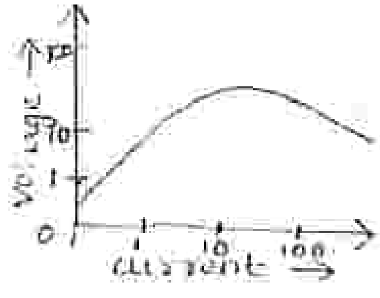
They have a very non-linear resistance-temperature relation.

The resistance R of a thermistor at a temperature T can be given by the equation,

$$R_T = \alpha e^{\beta/T}$$

α & β are constants depending on the material used.

2) Voltage - current characteristic :-



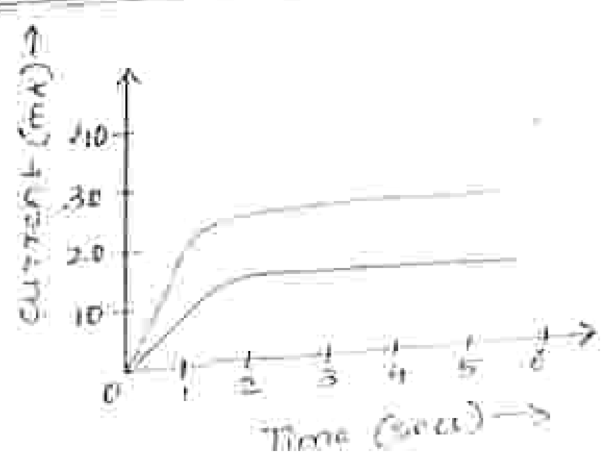
The characteristic is shown in fig.
From this characteristic it is clear that the voltage drop across a thermistor increases with the increase in current. After it reaches a peak value, the voltage drop falls with increase in current.

When a very small voltage is applied, the resulting current does not produce sufficient heat to raise the temperature of the thermistor. Under this condition, the thermistor obeys Ohm's law, ie the current is proportional to the applied voltage.

When larger voltages are applied, large currents are produced and as a result heat is produced to raise the thermistor temperature above ambient and hence its resistance decreases.

The current continues increasing until the heat dissipation of the thermistor becomes equal to the power supplied to it.

3) Current - Time characteristics:-



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These characteristics indicate the time delays to reach maximum current as a funct of the applied voltage.

THERMOCOUPLE :-

* Most simple and most widely used devices for measurement of temperature

* It consists of two dissimilar metal wi A and B, insulated from each other but welded or attached together at their ends forming two junctions.

T_1 & T_2 → Thermojunctions.

When one end of each wire is connected to a measuring instrument, it becomes an accurate and sensitive temperature measuring device

PRINCIPLE OF OPERATION :-

* It is based on Seeback effect

* If two wires of different metals are joined together at each end and form a complete electric circuit, then current flows in the circuit when the two junctions are kept at different temperatures

* This current is caused by an emf called the thermoelectric emf, set up in the circuit. This temperature difference of this two junctions is the cause for this emf.

* This thermoelectric emf is the same for any particular pair of metals with two junctions at particular temperatures. It is not affected by the size of the conductor, the area in contact or the method of joining them.

* The reverse of Seeback effect is <u>Peltier effect</u>

* Peltier observed that when an electric current flows across a junction of two dissimilar metals, heat is either generated or absorbed depending upon the direction of flow of current.

* Another reversible heat flow effect is the <u>Thomson effect</u>.

* When current flows through a conductor having a temperature gradient along its length, heat is liberated at any point where the current flow is in the same direction as the heat flow, while heat is absorbed at any point where these are opposite.

* It is to be noted that heat proportional to I^2R is generated in a current carrying conductor, raising the temperature above its local surroundings

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The total emf set up is made up of a part due to the peltier effect, which is localized at each junction and a part cause by the thomson effect, which is distributed along each conductor between the junctions

* Peltier emfs $\propto$ to the junction temperature.
* Thomson emfs $\propto$ (temperature difference)^2.

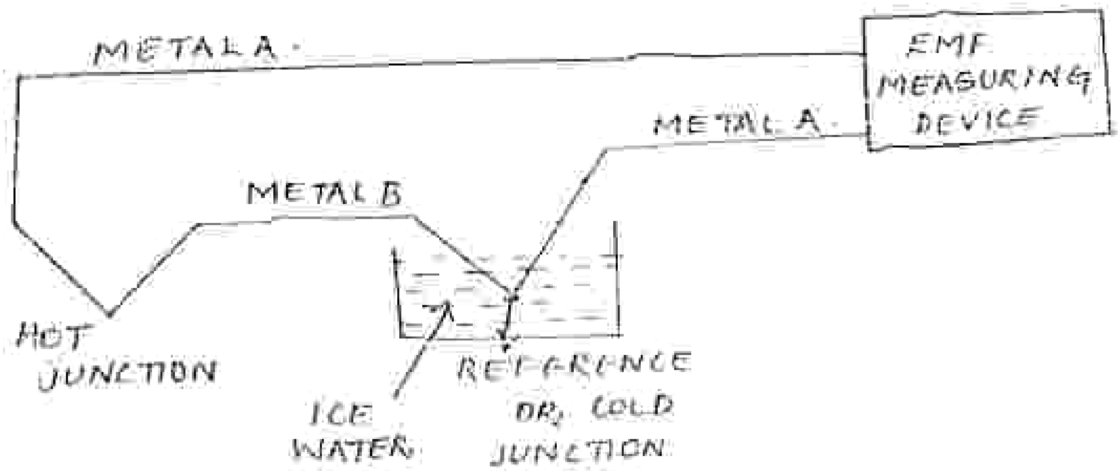
Thermo emf

$$E = \alpha (T - T_0) + \beta (T - T_0^2)$$

α + β → constants depending on the metals &
T → absolute temperature of hot junction.
T_0 → absolute temperature of cold or referen junction.

$E = \alpha (T - T_0) + \beta (T - T_0^2)$

Measurement of thermocouple Output :-



* For measurement of medium and low temperatures, the temperature of cold or reference junction is important.

* For measurement of high temperatures, the normal room temperature is sufficiently stable.

* This may be achieved by immersing the junction in an ice-water mixture.

* The output emf of a thermocouple can be measured by,

i) a sensitive PMMC millivoltmeter.

ii) a dc potentiometer.

iii) by a highly sensitive digital voltmeter.

MERITS :-

1) Thermocouples are rugged in construction and can withstand high shock.

2) They can be made in very small sizes.

3) They are cheaper than resistance thermometer.

4) The temperature range of thermocouples is about 1400°C. Cooler thermocouples can operate upto 1000°C.

5) They can be made from wire pairs as small as 0.013 mm in diameter for millisecond response.

6) They can be made from heavy-gauge wire to withstand the most severe applications.

DEMERITS :-

1) They have less accuracy than RTD or Thermistor

2) Accuracy ranges from ±0.25 to ±1 per cent.

3) For per degree of temperature, it must resolve tens of micro volts.

3) Needs protective covering when ... used employed at elevated temperature

4) Need compensating leads as these are placed remote from measuring devices.

5) Reference junction compensation is required in thermocouples

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NEED FOR INSTRUMENTATION SYSTEM :-

An instrumentation system is an assem[illegible] of devices combined together by some form [illegible] regular interaction between them.

The instrumentation systems can be classified into 2 major categories:

1) Analog Systems :-

* deals with information in analog form

* An analog signal may be defined [illegible] a continuous function ~~with~~ of time

2) Digital Systems :-

* A digital quantity may consist of [illegible] number of discrete or discontinuous pulses

* Deals with digital signal.
